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ABSTRACT

Presented is a National Science Foundation (NSF) sponsored report on a study of the university role in continuing basic research in the United States. The study, designed to provide a basis for future governmental policy formation, examined the critical question: How can the intellectual power and social benefits of the research enterprise in the nation's universities be preserved? The study grew from the apparent paradox that while university enrollment and research funding have declined sharply, there is no shortage of scientists and scientific advancement appears to be continuing unimpaired from the levels of the 1950's and 1960's when basic research was highly funded. The report resolves the apparent paradox in revealing that there is a lag of several years between initiation of experiments and disclosure of findings. Thus, current success in scientific research appears to be the fruit of the support provided years earlier. If continued success is to be maintained years in the future, total support of the sciences and research must be maintained today. (SL)

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The State Of Academic Science

The Universities in the Nation's Research Effort

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Bruce L. R. Smith and Joseph J. Karlesky

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Foreword

Over a period of about three decades—from 1940 to 1970—this country built a system for simultaneously expanding the quantity and the quality of research conducted in the nation's laboratories. Federal funds were the prime energizing force for this development, particularly in the basic research sector.

During this period of continuing expansion, students, scientists, and the universities, which conduct most of the nation's basic research, were the beneficiaries of an extraordinarily fruitful set of interlocking developments. Undergraduate enrollment increased steadily, generating a large demand for college and university teachers. Graduate enrollment and PhD output increased, stimulated by federal fellowships and research funds. The graduate students studied, taught undergraduates, and carried on research. The new PhDs became teachers and supplied the talent for the expanding national research effort. The steadily growing volume of federal research support generated a continuing stream of research findings that put this country firmly in a position of leadership in virtually all fields of science.

However, this fortuitous set of circumstances began to fall apart in the 1960s and early 1970s. Undergraduate enrollments have leveled off and so has research funding. Fewer new teachers and teaching assistants are needed, yet the number of new science and engineering PhDs produced each year continues at high levels. For the first time in 30 years, there is no shortage of scientists and engineers.

At the same time, universities are caught in a closing vise. Income from both public and private sources has been rising slowly while costs have escalated sharply. In spite of economies and efforts to increase income, universities have found that the resources required to sustain internal flexibility and the capacity for innovation have virtually disappeared. Instrumentation is obsolescent. The flow of younger people into

the system is decreasing dangerously.

Yet in the face of these developments, scientific findings of great significance in all fields continue to occur in undiminished quality and quantity. Those who assess the health of the nation's research system in terms of the products of science have seen no cause for alarm.

The signals seem contradictory: On the one hand, there are clear signs of decay; on the other hand, the quality of science appears unimpaired when one looks at the record of achievement, symbolized most dramatically by America's clean sweep of the 1976 Nobel Prizes. In the face of this apparent paradox, the National Science Board and the National Science Foundation were not certain they could provide sound advice on federal policy. In the Executive Branch, the Office of Management and Budget (OMB) reached an early, firm decision that federal support for graduate students should be cut back sharply, and this was done. But OMB policy on federal support of academic science was not as clear as its policy on support of graduate students, and with good reason: OMB had no better information on the situation than did the National Science Board. University presidents shared this lack of understanding; they all had a firm grasp of developments in their own universities, but none had an overall view. It has become increasingly urgent to obtain a clear, objective assessment of a most complex and confusing situation because both the government and universities are, to a great extent, setting policy on the basis of rumor and anecdotes of undoubted veracity but unknown representativeness.

Recognizing the importance of the question and the inadequacy of available information, the National Science Board and the National Science Foundation initiated complementary efforts to raise the level of understanding. An extensive survey, administered by the National Science Board, served as the basis for *Science at the Bicentennial* (1976). A second effort, also supported by NSF, is presented in this volume and its companion volume, *Working Papers*.

A major contribution of this book is its clear resolution of the apparent paradox. There is now no doubt that academic science has decayed in recent years. Many fields of science are not being explored with the vigor that characterized the 1960s. The real decay of instrumentation and physical plant hampers investigation. Some fields are not attracting the brightest young people.

The conclusion to be drawn from the continuing flow of first-rate scientific discoveries is not that the outlook is good, but that our vast and powerful system for academic science has tremendous inertia and that there is a lag—often several years—between the initiation of experiments and the disclosure of findings. The recent decay of the system will not be clearly manifest for several years. By that time, unless corrective action is taken, the motion of the system will be as strong downward as it was upward in the 1960s. If this is permitted to happen, we

will have to restore the health of the enterprise and the nation will be weaker for its lack of foresight.

In a sense, it is unfortunate that there is no crisis, because the nation tends to react to dramatic crises. The closing of a major university would probably produce action, but this will not happen. What will happen, unless a solution is implemented, is erosion on a scale that will harm the nation much more than the closing of a single university.

The most important part of this report is the accumulation and assessment of evidence on what is happening to academic science. If the thesis of the report, as it is outlined above, can be widely understood and accepted, corrective action will be taken. The President's budget for fiscal year 1977 proposed a substantial increase in federal support for academic science through an increase in the basic science budget of the National Science Foundation. The President's budget for fiscal year 1978 contained a substantial increase in the NSF budget for reinstrumenting the nation's laboratories. These steps were taken because the thesis of this report is beginning to be accepted.

Much more should be done, and specific actions are outlined in Chapter V. One of the most important policies relates not to money or to any specific legislation but to the way in which the federal government views universities. Ever since World War II, the federal government has regarded universities as places where research capacity can be tapped at will to produce findings of interest to federal agencies—including basic research. This is a profoundly inadequate view. Universities provide a unique environment for research and learning. The characteristics of that environment account for the fact that the center of gravity for basic research is in universities. If the federal government expects universities to continue to contribute in the future as they have in the past, attention must be paid to maintenance of their strength.

The observations, analyses, findings, and recommendations in the report do not constitute a report of either the National Science Foundation or the Association of American Universities. This report on the state of academic science is the responsibility of two social scientists who consulted a wide range of scientists, university administrators, and government officials. In particular, they relied heavily on the opinions of scientists for assessments of the vigor of science in the various fields discussed in Chapter IV.

The Association of American Universities is deeply indebted to Bruce Smith and Joseph Karlesky for a penetrating and stimulating examination of an important issue of national policy—the prospects for the continuing vitality of academic science.

Charles V. Kidd
Executive Secretary
Association of American Universities
May, 1977

Preface

There has been a growing debate in recent years over the size and direction of America's scientific research effort, an important part of which is carried out by the nation's major universities. Among the universities' principal concerns is whether the federal support of science and scientific manpower will be sustained. Federal and state governments are concerned about the mounting costs of higher education and are seeking ways to judge priorities in the support of university research: How much and what kinds of research are needed? And how should the effort be divided between universities and other research performers? These are some of the key questions that are now being raised. This study addresses itself to these and other issues.

This project grew out of discussions in late 1974 between Charles V. Kidd, Executive Secretary of the Association of American Universities, L. Vaughn Blankenship, Director of the Office of Policy Planning and Analysis of the National Science Foundation, and Bruce L.R. Smith, Professor of Government at Columbia University. Joseph J. Karlesky, Assistant Professor of Government at Franklin and Marshall College, joined the discussions in the spring of 1975.

The state of academic science has changed dramatically since the late 1950s: The Sputnik boom years of academic science support have ended and university scientists are facing a more constrained funding environment. It was apparent to us that an updated review, similar to Dr. Kidd's 1959 pathbreaking study, *American Universities and Federal Research*, was needed of the recent trends affecting the universities as research performers—a study that would go beyond the gathering of aggregate data to aid policy makers within both government and the universities. A thorough review of the issues, drawing on extensive site

visits to universities as well as other evidence, seemed important and challenging.

A grant to study "the future research role of the universities" was awarded by the National Science Foundation in June 1975, and our work was completed during the next 18 months. From the start, this effort was conceived as a wholly independent analysis to be conducted by the principal investigators with the assistance of many experts, advisors, and consultants but without any requirement for approval of the study's content or findings from any official body or organization.

In the course of the study we visited 36 universities and consulted with 383 university scientists and engineers, 180 deans and other administrative officials, 86 assistant professors, and 118 graduate students from these universities. In addition, we also held discussions with numerous officials throughout the federal government and with a wide variety of other informed individuals. The sample of universities chosen for site visits was based on a complex formula involving geographical considerations, size of research effort, and criteria related to institutional governance. Our aim was to achieve a very broad sample of the academic institutions that play a role in the nation's research effort. The sample of institutions visited can be classified in the following ways:

14 private universities
22 public universities

23 AAU universities
13 non-AAU universities

20 universities with an annual federally funded research effort of $15 million or more in 1974
16 universities with an annual federally funded research effort of less than $15 million in 1974

26 Carnegie I research universities
4 Carnegie II research universities
6 other

9 southern universities
10 western universities
10 eastern universities
7 midwestern universities

(No liberal arts colleges, other four-year colleges, or community colleges were visited.)

Site visits usually consisted of two-day stays by a four-member team and included interviews at the departmental and administrative levels. Depending upon the local circumstances and the availability of key personnel, we attempted to visit the following departments at each institution: physics, mathematics, chemistry, biology or life sciences, one engineering department (most often electrical), and one social science department. At the administrative level, the officials interviewed in-

cluded the chief academic officer (provost or academic vice president), the graduate dean, the individual responsible for research administration, the deans of engineering and/or medicine, and, in about one third of the cases, the president of the university. Without a doubt we trespassed on the time of many people far beyond the limits of courtesy. We wish to thank them all for sharing so generously with us their hopes as well as their problems and their ideas.

To an exceptional degree this study is a product of group deliberation and collective effort. We are most grateful for the generous help of the many people who assisted us in this undertaking. We take particular pleasure in a special word of thanks to the members of our advisory committee for the project. The advisory committee met six times over the 18-month period, giving advice and suggestions on all aspects of the effort from early research design to final drafting. Many members of the committee participated in site visits and contributed long and thoughtfully written critiques of early drafts. Two wrote working papers on developments within their disciplines, and each met or talked with us frequently outside of regular meetings. They contributed more to this report than we could have reasonably hoped for. The members of the advisory committee are:

Paul Bortz, Head, Industrial Economics Division, Denver Research Institute, University of Denver

William D. Carey, Executive Officer, American Association for the Advancement of Science

John M. Deutch, Professor and Chairman, Department of Chemistry, Massachusetts Institute of Technology

Humphrey Doermann, Executive Director, The Bush Foundation, St. Paul, Minnesota

Wayland C. Griffith, Professor of Engineering and Director, Engineering Design Center, North Carolina State University

C. Payne Lucas, Executive Director, Africare, Washington, D.C.

Rodney W. Nichols, Vice President, Rockefeller University

David Z. Robinson, Vice President, Carnegie Corporation of New York

Harrison Shull, Professor, Chemistry, Indiana University

Gary A. Strobel, Professor, Plant Pathology, Montana State University

As the final draft of this study took shape, the advisory committee thought that it should not function as an editorial board much less a collection of individual referees on specific conclusions reached. Instead, the committee tried to sharpen points in the spirit of clarifying the crucial question of the study: How can we preserve the intellectual power and social benefits of the research enterprise in our nation's universities? The members of the committee have authorized us to record their belief in the soundness of the study's analysis and to express their

hope that the issues and findings will be given serious consideration.

A series of commissioned papers on special topics provided useful data and background analyses for this study. The background papers are published in this book's companion volume, *Working Papers*. We have borrowed freely from these papers in various parts of the text. Many sections of this report, especially Chapter II, draw heavily on the paper by Dael Wolfle, Professor of Public Affairs, University of Washington. Dr. Wolfle also read the entire manuscript in draft form and offered valuable comments. Parts of Chapter II are derived from the paper by Walter S. Baer, Senior Staff of the Rand Corporation, and Chapter III is wholly his work. All of our data on graduate student trends in chemistry, physics, and mathematics originated in the paper by David W. Breneman, Senior Fellow of the Brookings Institution. The paper by Sanford A. Lakoff, Professor and Chairman of the Department of Political Science, University of California, San Diego, was very helpful in formulating the analysis of government/university relations given in Chapter V; and the paper by Carl York, a private consultant in San Francisco, California, contributed to the discussion of targeted research in Chapter II.

The following individuals also contributed background papers or thoughtful critiques of various sections of the study: Stephen P. Dresch, President of the Institute for Demographic and Economic Studies, Inc., New Haven, Connecticut; Edward K. Hamilton, Professor at the Graduate School of Business, Stanford University; and Raymond J. Woodrow of the Office of Research Administration, Princeton University.

In preparing the overviews of trends in the specific disciplines presented in Chapter IV, we were fortunate to have the help of outstanding individuals in those fields. Each reviewed our interview notes and prepared a working paper on background trends and problems in the discipline. These background papers and the contributors' critical analyses of our assessments were of invaluable assistance. In acknowledging their help, we do not wish to suggest that they necessarily agree with or endorse the interpretations we have finally presented: Sherman Beychok, Alan H. Kempner Professor of Biological Sciences and Chairman of the Department of Biological Sciences, Columbia University; D. Allan Bromley, Henry Ford II Professor of Physics and Chairman of the Department of Physics, Yale University; Kenneth Hoffman, Professor of Mathematics and Chairman of the Department of Mathematics, Massachusetts Institute of Technology; Warren E. Miller, Professor of Political Science and Director of Political Studies, Institute for Social Research, University of Michigan; Wayland Griffith, Professor of Engineering and Director of the Engineering Design Center, North Carolina State University; and Harrison Shull, Professor of Chemistry, Indiana University.

Another important aspect of the study was the gathering of data on the flow of federal research monies to different science fields and types of universities. Ivars Zageris, a private consultant in Washington, D.C., who worked with the American Council on Education and the President's Panel on Biomedical Research in assembling the life sciences data base, assisted us during a four-month period, setting up a computer program for our data base as well as helping us in the interpretation and use of quantitative data for the study.

Our colleagues at the Association of American Universities played a large part in making this effort possible, and they deserve much of the credit for seeing the task through to completion. Charles Kidd provided constant encouragement and expertise. The section on indirect costs in Chapter V is Dr. Kidd's work; it has been incorporated into the text with only minor revisions. Bernard V. Khoury, Senior Staff of AAU and a specialist in the problems of graduate education, contributed invaluable assistance and frequently participated in site visits. John Crowley, Senior Staff of AAU, also joined us on a number of site visits and rendered valuable assistance.

Vaughn Blankenship of the National Science Foundation was an ideal program manager, lending support and encouragement when needed and stimulating us to press further when we sought to take refuge in equivocation. His own standards of social science research helped greatly in the design and execution of the study. His NSF colleagues, in particular Carlos Kruytbosch, Luther Pickrel, and Israel Warshaw, also provided valuable assistance.

We sought out frequent opportunities to discuss our approach, tentative themes, and findings with a number of groups and organizations: the Committee on Science and Public Policy (COSPUP) of the National Academy of Sciences, the Committee on Federal Relations and the Council of Deans of the AAU, the National Conference on the Advancement of Research, and the Brooks Panel of the Office of Technology Assessment. We organized a conference with representatives from government and the research community to discuss our tentative findings. Harvey Brooks, Professor of Technology and Public Policy at Harvard University and chairman of an effort similar to ours for the Office of Technology Assessment, was particularly generous with his time and contributed helpful and perceptive criticism of various drafts. Drafts of the chapters dealing with the disciplines were discussed with NSF program officials in the relevant divisions. Many useful suggestions resulted from this exchange of views.

We also acknowledge with thanks the assistance of Milton Muelder of the Michigan State University Research Foundation, who undertook three site visits and wrote a careful, detailed summary of each, and that of D.C. Spriestersbach, Vice President and Graduate Dean of the University of Iowa, who participated in several site visits and aided us in

many other ways. Elmer B. Staats, Comptroller General of the United States and Morton Myers of the General Accounting Office staff deserve our warm thanks for suggesting topics for study, reviewing drafts, and providing encouragement and assistance.

It is a special pleasure to acknowledge the role of our editors in the publication of this study. We were fortunate to have excellent staff support from the editors of *Change* Magazine, a nonprofit corporation devoted to academic issues, to assist us in the complex task of readying the manuscript for publication with its numerous tables and figures. George W. Bonham, editor-in-chief of *Change*, believed in the national importance of this study and worked hard to make its early publication possible. Joan L. Stableski greatly improved the manuscript by her skillful editing and management of the production of the book. We are also grateful to Daniel W. Gottlieb for his editorial assistance on an earlier draft.

A grant from the Alfred P. Sloan Foundation assisted in the publication of this book and the companion volume of working papers. The Brookings Institution, although not responsible for the results of the study, provided us with working space, access to its library, and a stimulating research environment for the duration of the project.

We are greatly indebted to Susan Papenfuss, our research assistant, who performed a variety of tasks with great skill. Elliot F. Gerson of the Yale University Law School, who worked with us over the summer of 1976, was an extraordinarily valuable and stimulating colleague. Finally, we would like to express our appreciation to our families, especially our wives, Elise and Audrey, who bore the brunt of long absences while we were on the road.

Bruce L.R. Smith
Joseph J. Karlesky

I

The Universities' Role in the Nation's R&D Effort

Since World War II, America has become a world leader in science and technology. The partnership between the scientific community and the federal government, whose share of support for the nation's research effort has grown from 20 percent in 1940 to 53 percent in 1975, has been instrumental in achieving this high level of scientific excellence. The largest share of the basic research effort in this country continues to be borne by our major research universities, and the future of America's science and engineering effort will in part depend on their continued vitality.

This study reviews the recent trends influencing academic science and seeks to assess the prospects for the future. The basic findings are seemingly contradictory: While research of the highest quality continues to characterize academic science, with sometimes exceptional achievements, there are also the beginning signs of deterioration. A significant underlying problem that heightens the impact of adverse trends is the weakening financial condition of many universities. Important choices about the research role of universities in the next decade will be posed in an atmosphere of rapid change.

Chapter I

The Universities' Role in the Nation's R&D Effort

The scientific and technological capabilities of this nation are among its most vital assets. Its standard of living, the quality of its health care, the ease of travel and communications, its military strength, and innumerable other benefits of American life have been directly influenced by the quality and dynamism of the nation's science and technology. A strong science and technology capacity will remain of undiminished importance as we look ahead to an uncertain world of mounting energy crises, environmental dilemmas, and shortages of food and materials. Controlling pollution, protecting the environment, enhancing food production, expanding energy resources, securing substitutes for scarce materials, controlling mental illness, eliminating cancer, predicting earthquakes, maintaining the nation's security, and other desirable national goals will depend upon scientific knowledge and technological capacity. And in an increasingly competitive world economy, continued American scientific and technological leadership is an essential national goal.

The federal government's emerging partnership with the universities and its role as a purchaser of industrial research from private-sector firms are two of the striking developments of the postwar era. Government sponsorship of research activities under contract and grant arrangements has shifted dramatically: In 1940 the federal government provided only 20 percent of the total research and development (R&D) expenditures in contrast to 53 percent in 1976. America's universities have benefited enormously from this development, and they have consistently received the largest share of federal research funds allocated to the support of basic research (see Chapter II).

The tangible results of this increased investment are impressive, even if the government partnership with universities and industry in

the performance of R&D is of relatively recent origin. Some of the consequences are suggested by the following indicators:

> Between 1953 and 1973 the U.S. produced 65 percent of the 492 major technological innovations developed throughout the world. (Great Britain was second with only 17 percent.)
>
> The U.S. has been consistently selling four to five times more technical know-how to other nations than it has purchased from them during the period 1960-73.
>
> The level of U.S. productivity (Gross Domestic Product per employed civilian) exceeded that of all other major R&D performing nations between 1960-74.
>
> The U.S. led or equaled other major research performing countries in the number of citations in a large sample of the 1973 literature, ranking highest in chemistry and physics.[1]

The quality and vigor of American research are also confirmed by the number of scientific prizes won by American scientists in the past quarter century. The most widely recognized award for outstanding scientific accomplishment, the Nobel Prize, is awarded annually in the fields of physics, chemistry, physiology, medicine, and, more recently, economics. The distribution of these awards provides a useful index of a nation's standing in world science. In the 29 years following the resumption of the awards in 1943, Americans received 86 Nobel Prizes out of a total of 178 awarded in the sciences. In 1976 all of the Nobel Prizes in the sciences were awarded to Americans. Almost all of our Nobel Prize winners did their research at a major American university.

Yet the past decade has been one of substantial change for U.S. science and for the universities. Some disturbing trends have appeared. Although the U.S. remains a leading scientific nation by almost any indicator, the nation's relative standing in science and technology has fallen in several respects. The U.S. share of the world's scientific publications in various fields, the percentage of its Gross National Product devoted to R&D expenditures, its patent balance with a number of other countries, and various other factors now show a slight decline relative to other nations heavily engaged in R&D activities.[2] The long-term vitality of the nation's scientific enterprise has consequently been questioned, especially since adverse changes may become fully apparent only after a lead time of several years. Many fear that the U.S. may begin to lose its technological leadership and competitiveness in the world economy. This broad concern over American science and technology led to the passage of the National Science and Technology Policy, Organization, and Priorities Act of 1976, which reestablished a science advisory apparatus within the office of the President empowered to consider "ways to strengthen the nation's academic institutions' capabilities for research and education in science and technology."[3]

Study Objectives

To what extent is this nation committed to continued excellence in science, and what is the role of the universities in the national R&D effort? This study addresses itself to this central question. We have not considered all of the 3,000 American colleges and universities or the complete range of functions associated with them. Our focus is on the universities, public and private, that are heavily engaged in research activities. This group includes: (1) the large universities with significant graduate programs; (2) the specialized technical and engineering institutions; (3) the service universities with a primary orientation toward applied research in agriculture, mining, or mechanics; and (4) other academic institutions with research programs of importance. This study investigates the universities' capacities for conducting research of high quality and their closely related function of producing highly trained technical manpower for the nation.

We begin our analysis by posing this question: What are the significant trends of the past several decades that have affected the academic research effort? This is the subject of Chapter II, which relies primarily on aggregate data sources and trends in the patterns of support for academic research. Chapter III addresses itself to the changing relationships between universities and other R&D performers. Having outlined the important recent trends and institutional relationships, we devote substantial attention in Chapter IV to the current developments within the major fields of science and engineering. The perspective here is that of the working levels of scientific activity—the academic departments, institutes, and centers doing actual research. Our analysis is based on site visits to 36 universities, on the assessment of authorities in the various fields, and on aggregate data on the flow of federal research funds to different fields and universities. Chapter V is an analysis of the major emerging problems affecting the academic research effort as a whole and the strength of the institutional base for conducting research. Finally, on the basis of past trends, current developments, and emerging problems, an assessment is made of the special concerns for future public policy.

Basic Findings

The basic findings of this study may appear contradictory: We have been impressed by the strength and vigor of the academic science enterprise in the United States and by its continued ability to serve a variety of important national needs in research and in the training of high-quality manpower. The current period has been one of exceptional and even spectacular achievements in some fields. Generally, research of high quality continues to emerge from the laboratories of American

universities across a variety of fields. There has been no breakdown in morale or commitment among the nation's academic scientists or any significant group of them. Contrary to some fears, nothing resembling a collapse of the research climate has occurred at the major research-intensive universities. A surprising resiliency of the higher educational system exists in adapting to substantial changes in the conditions of basic research. In some respects a more favorable climate for research and scholarly activity exists now than did a few years ago, primarily because the student turmoil and related tensions of the late 1960s and early 1970s have passed.

There is another side, however: There is also evidence of a growing atmosphere of uncertainty and anxiety about the future. The factors contributing to the apprehension include:

- the decline of research opportunities for young scientists;
- a tendency toward less diversity in funding sources and toward conservatism in the choice of research topics;
- the deterioration of instrumentation and other supporting resources for academic research; and
- a subtle extension of inflexible controls that limit the individual researcher's freedom of action.

Such factors have tended initially to affect the less well-established and less distinguished departments and universities, but they are beginning to spread to many of the stronger centers of academic science as well.

A significant underlying problem is the weakening financial condition of many of even the wealthier universities. Although federal support for research has remained substantial, external economic pressures have forced cutbacks at public and private institutions, and the overall situation in recent years has been one of increasing financial austerity. Rapid inflation has escalated the costs of running a university. Simultaneously, the general economic slowdown (and only partial recovery) has depressed the value of endowments and reduced tax dollars available for education.

These broader economic forces, rather than a sharp drop in direct federal support for academic research, have had the greatest impact on the universities. The research-oriented universities are expensive to operate; in addition to supporting instruction, they must absorb the costs of research facilities such as libraries, laboratories, elaborate equipment, technical support personnel, and the like. Furthermore, universities, as labor-intensive institutions especially sensitive to inflationary pressures, lack mechanisms to offset the impact of escalating payroll costs. Thus the base on which the academic research enterprise rests is in jeopardy.

Financial cutbacks are not the only source of acute strain on academic science. The task of university management has grown more and more complex in recent years, and increasing administrative burdens have been passed on to department chairmen and senior research scientists. The degree to which universities are able to control their internal affairs—and in the broadest sense determine their destinies—appears to have diminished. Federally mandated social regulations, the actions of state coordinating bodies, the emergence of clerical employees' and technicians' unions, pressures for faculty unionization on some campuses, demands for student rights and pressures for better teaching, closer audit scrutiny—all these have had an impact on traditional governing procedures. Even the private institutions, by virtue of being large-scale recipients of public funds, have become subject to requirements for greater public accountability.

Universities, of course, cannot and should not expect to avoid the social responsibilities incumbent upon them. Many of the new obligations universities have assumed, such as the goal of equal access, are of paramount social importance. In some instances, however, problems have developed because of awkward mechanisms ill suited to the purposes sought or because administrative deficiencies on the part of both government and the universities have created unnecessary conflicts. To some extent federal and state reporting requirements for indirect cost allocations and faculty time spent on outside activities have risen faster than the ability of university administrations to cope with them.

A decrease in student enrollments is another source of strain for the academic research system. For most of the 1960s American universities experienced an unprecedented surge in enrollments, benefiting science greatly: Staff were added, facilities expanded, and commitments to new research arenas were made. In the 1970s, however, smaller numbers of students, especially graduate students (traditionally considered a vital part of the academic research effort), have resulted in sharply altered expectations. Proposals for significant changes in graduate education have inevitably arisen.

In 1976 the National Board on Graduate Education, calling attention to enrollment projections for the next decade and the declining job market for PhDs, appealed for important reforms of graduate programs. In particular the Board recommended increased experimentation with "nontraditional programs" serving "new clienteles." The Board concluded that "graduate education must make the transition from a system that has tended to follow a single model of advanced education to increasing diversity required by changing demographic, economic, and social circumstances."[4] The implications of such proposals for academic research efforts are far reaching and suggest the nature of the self-appraisal process now under way in many universities.

Some difficult and important questions will be raised in the decade

ahead as American universities seek ways to adapt to changing conditions. What level of which kinds of scientific research is it necessary to maintain as a matter of policy? And in which universities? What is to be the link between instructional and research functions; the relationships among universities, industry, and government agencies in the conduct of research; and the faculty and administrative responsibilities for decisions? These are certain to be among the important issues that will be debated vigorously.

Although American science and technology remain generally strong, competitive, and dynamic, sufficient warning signs of emerging problems have arisen to alert policymakers to ensure that these downward trends do not worsen. This study makes no pretense of having resolved all of the important issues concerning academic science that this nation will need to face. But we hope that the analyses and recommendations presented here will provide some of the background and perspective needed for that effort. In that hope, we address this study not to the academic and science communities alone but to federal and state governments, industry, and foundation officials, as well as to an informed public—all of whom will have to make choices affecting the future of academic science.

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1. National Science Board, *Science Indicators—1974: Report of the National Science Board, 1975* (Washington, D.C.: National Science Foundation, 1975), pp. 2-3, 19, 165.
2. Ibid., pp. 2-3.
3. Public Law 94-282. See *United States Code Service*, Lawyers Edition, Issue No. 6 (Rochester, N.Y.: Ninety-fourth Congress, Second Session, June 1976), p. 1586.
4. *Outlook and Opportunities for Graduate Education—The Final Report*, No. 6 (Washington, D.C.: National Board on Graduate Education, December 1975), p. 49.

II

Trends in the Support and Performance of Academic Research

The development of American science has been largely the responsibility of four major science sectors—government, industry, private foundations, and the universities. Integration of the scientific effort and the patterns of support for science among these sectors was a difficult process. In basic science a partnership between the federal government and the nation's universities emerged only after World War II.

Since the late 1960s, support for academic research has leveled off. The universities continue to be the predominant basic research performers. The Department of Health, Education, and Welfare now provides over half of all federal dollars going to university research. There has been a shift of research emphasis toward applied research in most fields. Among fields, the life sciences have grown rapidly. Recent trends suggest that investigators may favor "safe" research projects at the expense of the most inventive lines of inquiry.

Chapter II

Trends in the Support and Performance of Academic Research

Since World War II, the United States has built a strong and diversified research capability. Relying on the wartime practice of extensive contracting with outside performers, the federal government has provided funds to American universities, industrial firms, federally funded research and development centers (FFRDCs), and other institutions for a variety of research services. American universities became preeminent in many fields of basic science, and the U.S. gained a leading role in world science and technology.

The period following the launching of the Soviet Sputnik in 1957 was one of spectacular growth for the universities, and the growth in federal research support continued until the mid-1960s. The period since then has generally reflected readjustments to steady-state conditions. Substantial support still exists for university research, but rapid growth is a thing of the past. For many universities the adjustments to new circumstances have been difficult, but the university sector as a whole has retained and even consolidated its position as the principal performer of basic research.

Nonetheless, important changes have taken place in the past decade. These include greater emphasis on federal research support for applied work, a decline in institutional support, shifts in the dominant federal sponsoring agencies of university research, and declining student enrollments. This chapter examines the general structure of current university/government relationships. As a framework for later chapters, it identifies the direction and magnitude of important recent trends now affecting the research efforts of universities.

Historical Background

The federal government and science have long been joined in a close relationship. From the earliest days of the nation, the federal government was concerned with "the continuous spectrum of scientific activities, from the pursuit of knowledge for its own sake to intensive application of the fruits of research."[1] Reliance on the work of academic institutions and scientific societies for fundamental research dates back to the time of Thomas Jefferson. "A public institution," Jefferson said, "can alone supply those sciences which, though rarely called for, are yet necessary to complete the circle, all the parts of which contribute to the improvement of the country, and some of them to its preservation."[2] As historian A. Hunter Dupree characterized the early relationship: "From the beginning the federal government has rendered honor to science and profited from it. Almost as early, the support given by the government was a significant source of strength in America."[3]

The nineteenth century saw many examples of congressional action to support basic research, some of the most notable being the research effort of the Department of Agriculture, the establishment of the Coast Survey, and the founding of the Smithsonian Institution and the National Academy of Sciences. Significantly, the Morrill Act of 1862 provided public lands for the establishment of the land-grant colleges. By 1900 the federal government clearly recognized the need for specialized research institutions to carry out essential scientific work. Thus, the National Bureau of Standards was created in 1901, the Public Health Service in 1912, and the National Advisory Committee on Aeronautics in 1915. By this time America was well on its way to becoming a world leader in agriculture with the aid of a unique and flexible agriculture research service. And to meet the needs of the Army and Navy as well as a number of civilian agencies, an impressive federal scientific establishment with in-house laboratories took shape during World War I.

The developing pattern was not without serious faults. Four major sectors of science support—government, universities, industry, and private foundations—had developed along independent lines. As later became apparent, especially in the 1930s, their activities were not effectively integrated. Strong central leadership and coordination were lacking, and communication among the different parts of the system proved inadequate.[4] Moreover, the direct research efforts of the federal government through its in-house laboratories had declined by the 1930s in relation to other research institutions. Depression-era budget cuts caused many bureaus to lose their best scientists to other centers of research. Although the Department of Agriculture, with its experiment stations and land-grant colleges, maintained its high level of R&D, most other federal departments, including the military, were forced to cut back. In contrast, American universities, with the assistance of federal grant

programs to the states, enhanced their positions as performers of both basic and applied research—and most notably, in the case of applied research, with respect to agriculture.

Industrial research became significant to the national research effort at a later stage. After World War I, the number of industrial research laboratories markedly increased as more and more businesses found science useful for product development, testing, innovation, and diversification. In certain dynamic industries, such as specialty chemicals, pharmaceuticals, and electrical manufacturing, research was crucial.

From early on in the century, when the Rockefeller and Carnegie Foundations were established, private philanthropy also supported science. The Depression, however, affected the financial ability of the foundations to expand their support. Later, rising research costs excluded foundations from a major role as general supporters of scientific research, though they continued to figure importantly in some special program areas relating to manpower, research, and training.

The development of science support since the 1930s has been marked by growing interrelations within the system, with the federal government taking its place at the center. In basic research, the key to this development became the partnership between government and the universities. This partnership, still very weak in the 1930s, was forged during the Second World War, an event that decisively shaped the character of government/university relations. As research programs of the armed services proved insufficient to meet urgent wartime needs, the government turned to university scientists for major assistance. The new framework for government/university research relations was established in 1941. President Roosevelt then created the National Defense Research Committee (NDRC) and a year later expanded it into the Office of Scientific Research and Development (OSRD).[5]

OSRD operated no laboratories of its own but contracted with both universities and corporations. Through the contract mechanism, OSRD was able to press into government service whole institutions—such as universities and industrial laboratories—whose scientific resources were deemed necessary to the war effort. In the process, important precedents were set for the future partnership between government and universities in support of scientific research. The contracts set standards for determining costs and outlining mutual responsibilities between the fiscal and scientific officers in government and the administrators and principal investigators in universities. Moreover, guidelines were set in matters dealing with patents, security, and the disposition of property. No distinctions were made between public and private universities. When work could be done on a small scale, individual researchers were awarded research assignments; when a larger scale effort was necessary, a qualified institution was chosen. Some major centers at universities, the Radiation Laboratory at the Massachusetts In-

stitute of Technology, for example, became vital installations in the most sensitive areas of national security research.[6]

OSRD was established by executive order during a time of national emergency. Once the war was over, however, Congress was called upon to shape future federal science policy. In preparation for this public examination, President Roosevelt asked Vannevar Bush, then director of OSRD, to recommend future science support policy. In his letter to Bush of November 17, 1944, Roosevelt referred to OSRD as "a unique experiment of team-work and cooperation in coordinating scientific research and in applying existing scientific knowledge to the solution of technical problems paramount in war."[7] Roosevelt empowered Bush to assemble an advisory committee representing the scientific community to prepare the report. Bush's report, *Science—The Endless Frontier*, published in 1945, helped set the tone for postwar relations between government and science. The government was viewed as a central supporter and promoter of research capabilities:

> The government should accept new responsibilities for promoting the flow of new scientific knowledge and the development of scientific talent in our youth. These responsibilities are the proper concern of the Government, for they vitally affect our health, our jobs, and our national security. It is in keeping also with basic United States policy that the Government should foster the opening of new frontiers and this is the modern way to do it. For many years the Government has wisely supported research in the agricultural colleges and the benefits have been great. The time has come when such support should be extended to other fields.[8]

President Truman set the framework for the congressional debates on postwar science policy on September 6, 1945, when he said:

> No nation can maintain a position of leadership in the world of today unless it develops to the full its scientific and technological resources. No government adequately meets its responsibilities unless it generously and intelligently supports and encourages the work of science in university, industry, and in its own laboratories.

Truman expanded on the concept of "universities, industry, and government working together," while declaring that "although science can be coordinated and encouraged, it cannot be dictated to or regimented. Science cannot progress unless founded on the free intelligence of the scientist."[9]

Thus, even though the OSRD went out of existence after World War II, the foundation was laid for a national science support system. The formation of the Office of Naval Research (ONR) in 1946, followed by similar offices in the other services, reflected the military's desire to maintain their new-found partnership with science. The National Institutes of Health (NIH), which since its inception in 1930 had dis-

played an impressive intramural research operation, began a vigorous extramural grant program for general medical research once the OSRD Committee on Medical Research dissolved. The immediate postwar period also saw other agencies initiating programs of extramural research support. The Atomic Energy Commission (AEC) began to award project grants and contracts to university scientists. With the university-run laboratories inherited from the Manhattan Project, the AEC created a system of national laboratories that was instrumental in bringing the United States to scientific preeminence in many fields.

Despite the achievements of ONR, NIH, AEC, and other mission agencies, the government still had not fully and explicitly established the framework for postwar science affairs. In particular, it had not clarified the role of university science as a major national resource. Responding to this issue, Truman in 1947 appointed a President's Scientific Research Board under John R. Steelman. Among the Board's major recommendations in its report of August 27, 1947, were:

> 1. That, as a Nation, we increase our annual expenditures for research and development as rapidly as we can expand facilities and increase trained manpower. By 1957 we should be devoting at least 1 percent of our national income to research and development in the universities, industry, government.
>
> 2. That heavier emphasis be placed on basic research and upon medical research in our national research and development budget. Expenditures for basic research should be quadrupled and those for health and medical research tripled in the next decade, while total research and development expenditures should be doubled.
>
> 3. That the federal govenment support basic research in the universities and nonprofit research institutions at a progressively increasing rate, reaching an annual expenditure of at least $250 million by 1957.[10]

Thus, the basic decisions affecting postwar suport of academic research were made within a few years after World War II, and the pattern has persisted to this day: First, to assure that scientific research would further the broad aims and priorities of government as defined by the Congress and the President, federal research support would be closely linked to the operating missions of federal agencies. However, a smaller share of funds would be devoted to the general health of the basic sciences and to the research-related educational functions of universities.

Second, nongovernment laboratories would be relied upon to perform much of the research of interest to the federal government. But in-house laboratories would also play a strong role in total national research. What resulted was a division of labor, with some overlap of functions and competition among the different categories of research performers.

Third, direct relationships between federal agencies and university

researchers were established. Most funds for university research would be awarded to individual investigators or small teams of investigators rather than to the institutions themselves. (In a legal sense, the funds are awarded to institutions, but the decisions are based primarily on the merits of specific proposals and the scientific qualifications of individuals rather than on geographical or other formulas.)

Fourth, university research and graduate training were to be viewed as closely related functions, thus avoiding the pattern in some nations of separating advanced scientific training from research activities. Although the patterns that have developed are more complicated than these simple characterizations suggest, they broadly describe the central principles of post-World War II science policy in the U.S.

Support of Academic Research Since the 1950s

The 1957 launching of the Russian Sputnik triggered a spectacular expansion in the American research effort, lasting approximately a decade. From 1953 through 1967, national expenditures in current dollars for R&D grew by more than 350 percent (see Figure 1). The federal government increased its own R&D expenditures even more rapidly during this period—by almost 425 percent. By 1967, it was providing 62 percent of the national R&D investment. But since 1967, the growth rate has been far below that of the previous decade, and by 1976 the federal government's contribution to the total had declined to an estimated 53 percent.[11]

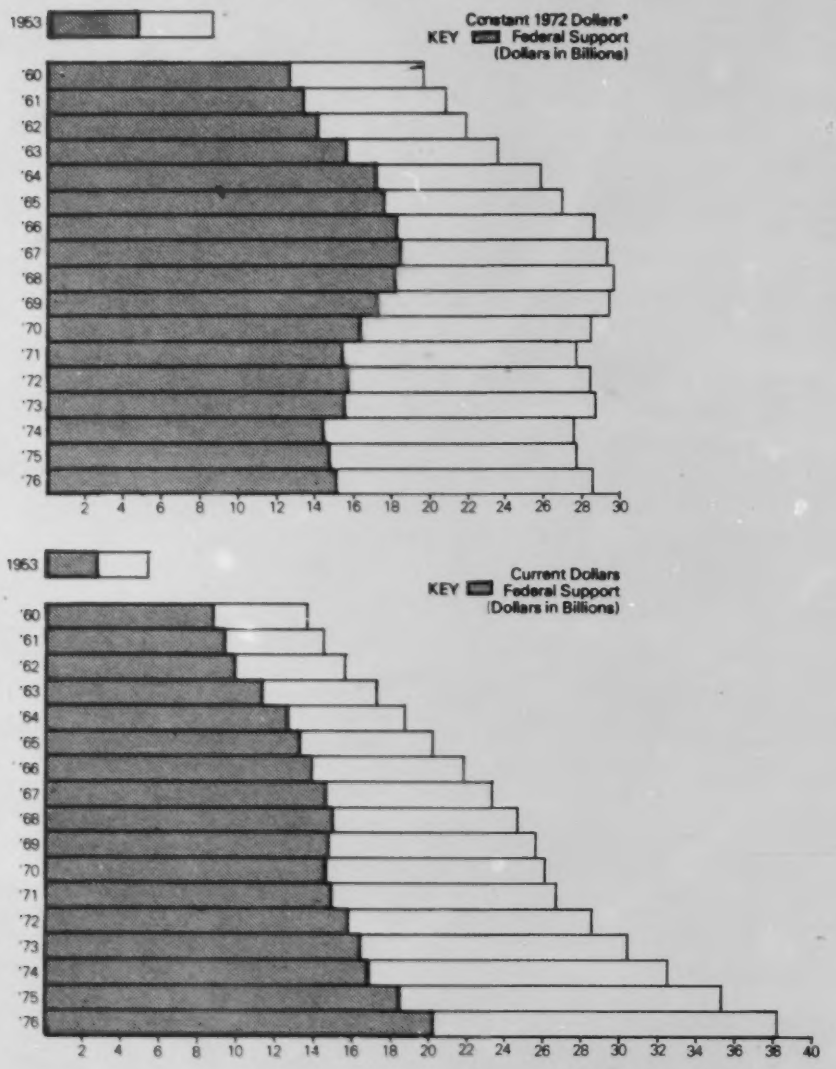
In constant dollars, growth from 1953 to 1967 can still be seen as proceeding at a very high rate. But after 1967, inflation rates were more rapid, and converting to constant dollars changes the picture dramatically. Seen in constant 1972 dollars, the national R&D total in 1976 was an estimated 3 percent below that in 1967, and the federal portion had declined by almost 18 percent over that same period.

As shown in Figure 2, university research and development funds in current dollars from all sources also grew rapidly in the period 1953-67. Academic science flourished, sponsored chiefly by the nation's mission agencies. The sum total of university R&D funds from all sources has continued to grow since 1968, even in constant dollars, but at a much slower rate. Constant dollar funds from all sources for total university R&D were estimated to be 6 percent higher in 1976 than in 1968, although the 1976 total was still lower than the peak level of 1973. Federal funds for university R&D have continued to grow in current dollars since 1968, but federal support in constant dollars has dropped by an estimated 3 percent over the period.

In regard to basic research the situation is more constrained. National basic research expenditures have decreased more sharply in

Figure 1

Expenditures for R&D
Total National Effort and Federal Support, 1953-1976
(Constant Dollars and Current Dollars)

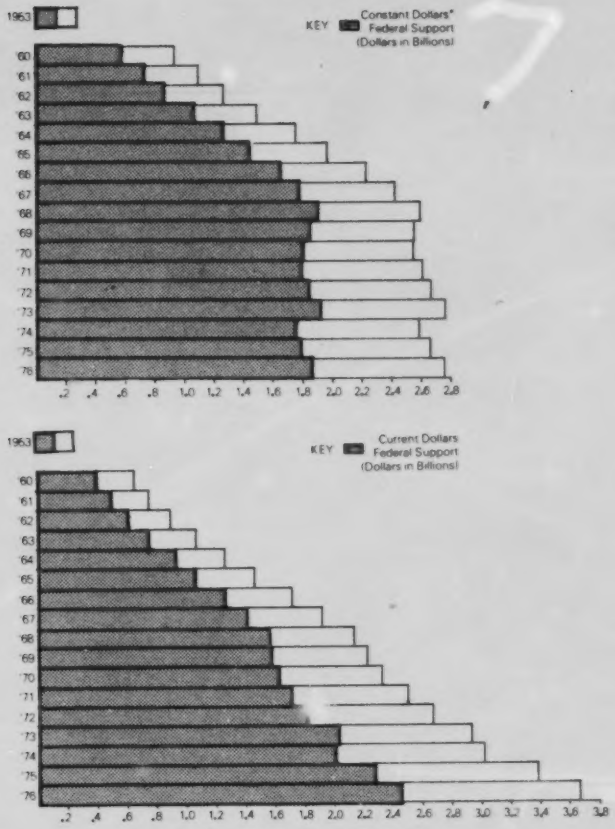


*Based on GNP implicit price deflator.

Source: National Science Foundation, *National Patterns of R&D Resources: Funds and Manpower in the United States, 1953-1976*, NSF 76-310, Table B-5, p. 28, and footnotes 1 and 2, p. 2.

Figure 2

University Expenditures for R&D All Sources and Federal Support, 1953-1976 (Constant Dollars and Current Dollars)



*Based on GNP implicit price deflator. The price deflator for the years 1953-71 has been taken from the Annual Report of the Council of Economic Advisors, *Economic Report of the President*, January 1976 (Washington, D.C.: U.S. Government Printing Office, 1976), p. 174. The price deflator for 1973 is taken from Bureau of Economic Analysis, *Survey of Current Business*, Vol. 56, No. 7, Table 1 (Washington, D.C.: U.S. Department of Commerce, July 1976), p. 1. Price deflators for the years 1974-76 have been taken from Bureau of Economic Analysis, *Survey of Current Business*, Vol. 56, No. 11, Table 23 (Washington, D.C.: U.S. Department of Commerce, November 1976), p. 100.

Source: Current dollar amounts have been taken from National Science Foundation, *National Patterns of R&D Resources: Funds and Manpower in the United States, 1953-1976*, NSF 76-310, Table B-1, pp. 20-21). R&D expenditures in colleges are included with university R&D expenditure data.

constant dollars than total R&D outlays.[12] Federal constant dollar expenditures for basic research declined by an estimated 15 percent between 1968 and 1976.[13] Since universities perform a large share of all American basic research, they have felt most sharply the constraints on such funding. In fact, in real dollars fewer basic research funds were spent in universities in 1976 than in 1968. Moreover, while actual federal support for total university R&D has declined by an estimated 3 percent between 1968 and 1976, support for university basic research dropped by 9 percent over the same period.[14] Because of this real decline in basic research support, the Ford administration included additional basic research funds in its fiscal 1977 budget request. As veteran science administrator Willis H. Shapley notes: "There is no doubt that the administration did something special for basic research in the FY 1977 budget. Apparently there was a specific last-minute decision to add $50 million for basic research to the previously decided NSF budget allowances."[15] Congress eventually approved $22 million of this requested addition.

In sum, constant dollar university research and development funds from all sources have grown slightly since 1968, but federal support has declined. Further, total support for basic research in universities—and especially federal support for such research—has declined. Consequently, although support remains at high levels, the atmosphere within which American science is conducted has changed from one of rapid growth and expansion to one of stability and even some contraction. Adjustment from the expansionary conditions of the fifties and early sixties is the basic circumstance that American universities have faced for nearly a decade. Many are still in the process of adapting their programs and policies to this changed environment.

Similarly, science faculty in recent years have grown at a much slower rate. Nevertheless, the number of scientists and engineers on university faculties has increased somewhat over the past decade. Seen in constant 1967 dollars, research expenditures per full-time equivalent scientist and engineer employed in universities granting doctoral degrees therefore decreased from $11,500 a year in 1966 to $8,400 a year in 1974. (In practice, of course, cuts have not been distributed evenly among all university scientists and engineers.)[16]

Funds for Universities and Other R&D Performers

Examination of funding patterns over the past 10 years reveals that universities have not suffered uniquely and in fact have done fairly well compared with other performers. The basic division of labor among the R&D performing institutions—universities, government laboratories, FFRDCs, industry, and nonprofit centers—has been maintained in the

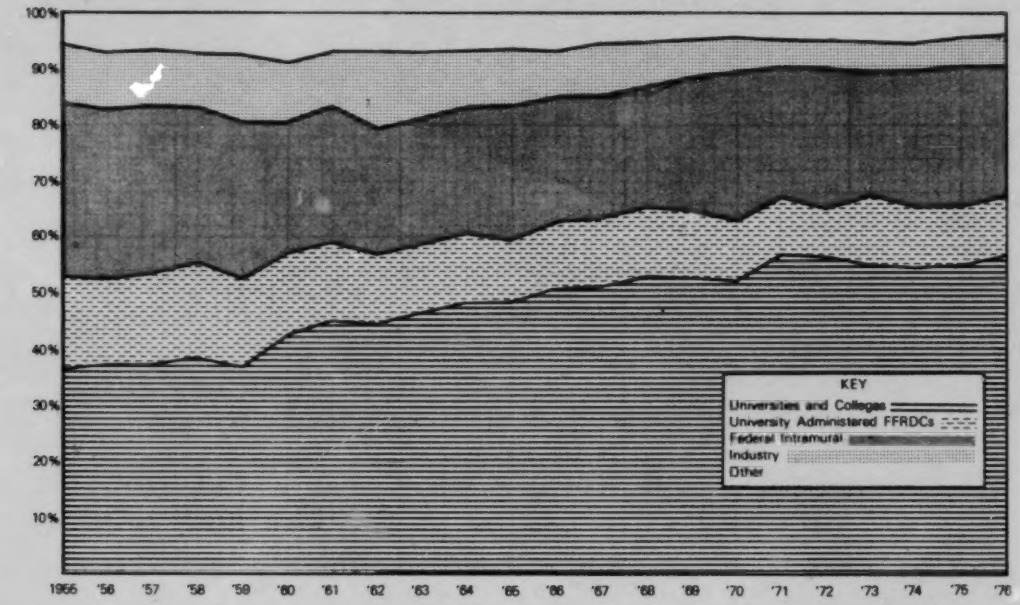
past several decades. Each sector, in varying degrees, has faced somewhat more austere circumstances. But basically the roles of the different performers have not changed. Development work—only rarely done by universities—remains largely the domain of industry. The task of basic research falls most naturally to the universities and, indeed, the position of the universities as major performers of basic research has been relatively strengthened. Government laboratories, FFRDCs, and nonprofit research organizations are primarily engaged in large-scale efforts often of an applied research nature, but they sometimes also perform basic research and, occasionally, development. Fears that campus disorders in the late 1960s and early 1970s would lessen congressional support for academic research have proven unfounded.

Trends among basic research performers can be most clearly discerned by noting relative changes in their shares of research spending. Universities and colleges, as shown in Figures 3 and 4, have experienced steady increases in their percentage shares of funding in basic research support. [17] The year 1966 was the first in which the university sector reported spending more than half of all federal funds for basic research—up from 36 percent in 1955. When applied R&D is included, the university share of total federal R&D spending is clearly smaller, but even this figure increased from 5 to 9 percent between 1955 and 1966. Furthermore, by the early 1950s, FFRDCs operated by universities had become, after universities and government laboratories, the third largest recipient of federal funds for basic research. In 1966, university-administered FFRDCs accounted for 11 percent of federal spending for basic research and 5 percent of federal spending for all R&D.

Since 1966, universities have received an increased share of federal and total funds for basic research. As of 1976, universities and colleges accounted for 55 percent of the total basic research funds, up from 46 percent in 1966 (see Figure 4). This increase was not as great as that in the preceding decade when the university share grew from 30 to 46 percent. Still, despite great fiscal pressures, universities managed to consolidate their position during the last decade as the predominant basic research performers in the United States.

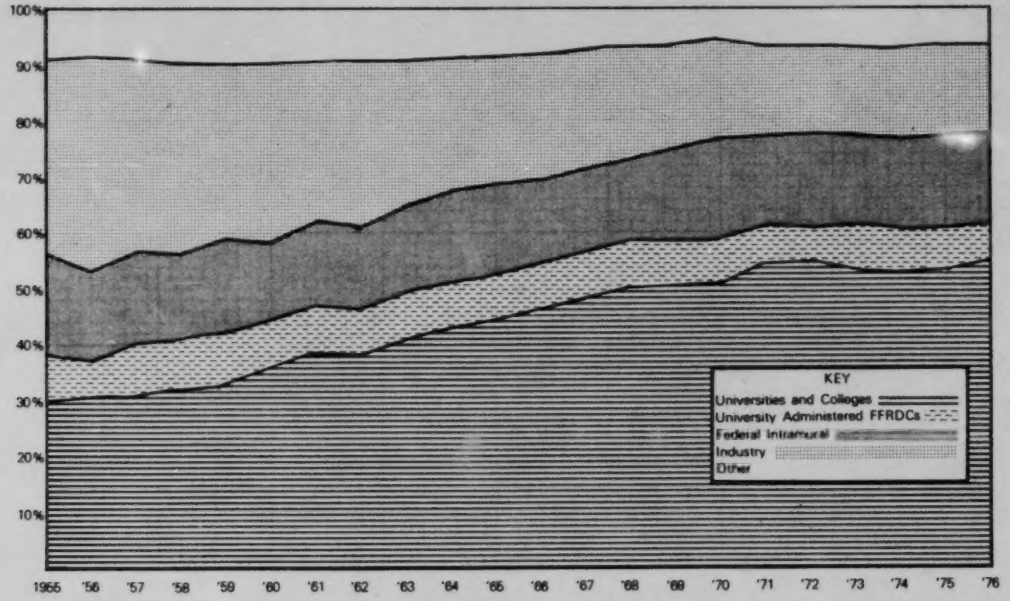
Concurrently, industry's share of basic research dollars has decreased. Total funds for basic research spent in industrial laboratories increased by 24 percent in current dollars between 1966 and 1976, still resulting in a drop in the industrial share from 22 percent in 1966 to 16 percent in 1976 (see Figure 4). This resulted from both an absolute drop in federal funding and only a modest increase in industry's own expenditures for basic research. Although total U.S. spending for basic research increased 68 percent in current dollars between 1966 and 1976, industrial firms spent only 34 percent more for such research.[18] The percentage of industry's own R&D funds devoted to basic research declined from 6.3 percent in 1966 to 3.7 percent in 1976. (The implications

Figure 3
Distribution of Federal Funds for Basic Research by Performer
1955-1976



Source: Data contained in National Science Foundation, *National Patterns of R&D Resources: Funds and Manpower in the United States, 1953-1976*, NSF 76-310, Table B-2, pp. 22-23. Data for 1975 and 1976 in the original table are estimates.

Figure 4
Distribution of Total Funds for Basic Research by Performer
1955-1976



Source: NSF (see Figure 3), pp. 22-23.

of this decline in industrial interest in basic research for university/industry relations are discussed in Chapter III.)

The federal intramural laboratories and university-administered FFRDCs have increased very slightly their shares of basic research spending—as percentages both of total funds and of federal funds during the past decade—even though there have been some changes in the sponsoring agencies. Similarly, the shares represented by the independent research centers and "other nonprofit institution" category have remained nearly constant. It is noteworthy that even the advent of federally funded large-scale research facilities in such fields as physics, astronomy, and oceanography has not significantly altered the university's leadership role in basic research. As David Z. Robinson, vice president of the Carnegie Corporation and long-time observer of science affairs, summarizes the evidence:

> Those who felt that the advent of expensive research tools would move the center of gravity of basic research from the universities to federally funded central laboratories have been proved wrong so far. Indeed, the central laboratories, although they are national facilities, are so organized as to consciously support university research groups. This support is secured by university domination of laboratory boards of trustees, by the predominance of outside users on advisory committees, and by the requirement that a large fraction of time be reserved for outside users.[19]

The universities' share of total R&D funds has not increased as significantly as their share of basic research funds. (Universities typically perform less than 1 percent of the development function.) The universities' share of total R&D spending grew from 8 to almost 10 percent during 1966-76, and their share of federal R&D spending increased from 9 to 12 percent.[20] The federal in-house laboratories' share of federal R&D spending increased somewhat more significantly—from 23 to 28 percent—during this period. Industry's share of federal R&D funds has declined.

Table 1 presents the percentage shares of R&D support by agency for each performer category in 1966 and 1976.[21] For example, the universities' share of R&D funding from the Department of Defense (DOD) has fallen from 4 to 2 percent during the past decade. Since DOD has been the largest supporter of research and development, this seemingly small percentage change represents a significant shift in resources. If universities had maintained their share of defense R&D during this period, they would have received about $200 million more in 1976, or nearly 8 percent more than the total federal funding for university R&D. The shift of defense R&D resources away from universities resulted from policy decisions made by Congress and the Department of Defense in the late 1960s. Between 1966 and 1975 DOD's in-house laboratories were the chief beneficiaries of these shifts in allocation of R&D

Table 1

Changes in Federal Agency Support of Research and Development by Performer, 1966-1976[a]

Department or Agency	R&D Obligations (Millions of $)		Percent of Agency R&D Obligations									
			Universities[b]		Univ-Affiliated FFRDCs		Federal Intramural		Industry[c]		Other	
	1966	1976	1966	1976	1966	1976	1966	1976	1966	1976	1966	1976
Defense	$7,023	$9,905	4%	2%	2%	2%	27%	30%	63%	64%	4%	2%
NASA	5,050	3,448	2	3	2	2	17	34	78	59	1	2
HEW	1,014	2,603	53	53	—	—	18	19	4	6	25	22
AEC[d]	1,212	2,804	7	5	32	27	2	4	55	61	4	3
NSF	227	623	79	73	7	8	6	8	1	3	7	8
Interior	143	330	14	11	—	—	66	61	10	27	10	1
Agriculture	235	478	26	26	—	—	70	73	1	—	3	1
Transportation	172	372	1	6	—	1	24	20	73	54	2	19
EPA	e	312	e	12	e	—	e	50	e	25	e	13
Commerce	55	239	7	10	—	1	76	67	16	13	1	9
Others	173	511	18	8	—	1	43	41	17	23	22	27
TOTAL	$15,304	$21,625	9%	12%	4%	5%	21%	27%	61%	50%	5%	6%

a. Figures for 1976 are estimates.
b. Includes funds obligated to universities and colleges.
c. Includes FFRDCs administered by industrial firms.
d. ERDA data for 1976. Does not include Nuclear Regulatory Commission.
e. Agency did not exist in 1966.

Source: National Science Foundation. *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years 1966, 1967, and 1968*, Vol. XVI, Table C-7, pp. 112-113. *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years 1975, 1976, and 1977*, Vol. XXV, Table C-8, pp. 14-15.

funds. Since 1975, DOD has changed its policy to increase the industry share of R&D funds at the expense of its in-house laboratories.[22]

The National Aeronautics and Space Administration (NASA) also decreased its funding of university R&D from $117 million in 1966 to $107 million in 1976. This drop, however, reflects the cuts in overall NASA programs after the manned lunar landing, rather than a selective shift away from support of university R&D. In fact, universities received a larger share of NASA R&D spending in 1976 than in 1966. There was also a shift of NASA R&D shares from industry to in-house NASA laboratories.

The three other principal patrons of university R&D—the Department of Health, Education, and Welfare (HEW), the National Science Foundation (NSF), and the Atomic Energy Commission (now a part of ERDA, the Energy Research and Development Administration)—have not significantly changed their percentages of R&D support flowing to universities during the past decade. HEW devotes a slightly larger share of its R&D funding to in-house research, but the university share has remained constant at 53 percent. NSF, despite an increased emphasis on applied research through its RANN program (Research Applied to National Needs), continues to devote nearly the same share to university R&D as it did in 1968 (the decrease from 79 percent to 73 percent is accounted for principally by the decrease in NSF funds to four-year colleges). The principal impact of the RANN program on research peformers appears to be the increased support of industrial R&D. Similar changes anticipated in energy R&D began to show up in the estimated 1976 figures for ERDA.

The new emphasis on civilian R&D in other federal agencies, reflected in Table 1, had not significantly affected university research support by 1976.[23] The Departments of Transportation, Justice, Labor, and the Environmental Protection Agency each increased the university components of their R&D programs. But because these programs are still relatively small, they have had little impact on the overall flow of federal R&D dollars to universities.

In general, the increased university share of federal R&D support during the 1966-76 period is due to larger R&D budgets in HEW and NSF, the two agencies that primarily emphasize university R&D. Yet the university share of federal R&D support seems unlikely to increase in the next decade as it has in the past, particularly if the federal government places greater emphasis on R&D directed toward civilian applications. Large R&D programs in energy, environmental protection, transportation, and so on are more likely to increase industry's share of federal R&D expenditures. ERDA, for example, is committed to large-scale development projects and commercial demonstrations of new energy technologies in partnership with industry. State and local governments may also be expected to increase their civilian R&D spending

as recipients of federal revenue sharing or direct R&D support, but some of these funds will in turn be spent in the university sector.

The picture that emerges from the foregoing analysis of performer shares of R&D expenditures is generally consistent with observations made during our site visits. Faculty members in leading departments commented as follows:

> Overall support is holding up pretty well.
>
> Most people who are good still get money for basic research.
>
> Some of our proposals are turned down, but the department hasn't lost any that I would really want to fight for.
>
> We are not really hurting too badly on grant money. We have a lot of problems, some that are getting serious, but this isn't one of them.

The slowdown in the growth of federal support in the past decade has affected all research performers somewhat, including those in the universities, but it has not yet seriously impaired research motivation. Yet some changes in research behavior seem to have occurred.

National surveys conducted in 1968, 1974, and 1975 of departments granting doctoral degrees all showed from 83 to 85 percent of the faculty members to be spending at least 20 percent of their time on research.[24] However, the percentage of these faculty members receiving federal support dropped from 65 percent in 1968 to 57 percent in 1974.[25] Moreover, in order to secure support a number of faculty members have had to shift their fields of research. In 1968, 78 percent of the doctoral-granting departments could report that their younger faculty members were able to secure support for the research areas of their choice; for senior faculty, that figure reached 88 percent. By 1974, the percentages had dropped to 56 percent for younger and 53 percent for senior faculty members.[26] Another study, based on 1975 data, found 31 percent of the doctorate-granting departments reporting that 10 percent or more of their faculty were conducting research in areas other than their preferred ones. However, only 8 percent of these were doing research in a field of science entirely outside of their chosen field.[27]

Nonproject Forms of Support for Academic Science

Although funds for specific projects have increased in current dollars during the post-1967 readjustment period, the more general support for academic science enjoyed in the post-Sputnik boom years has been substantially reduced. In 1967, in addition to federal obligations of $1,301 million for R&D projects, colleges and universities also received $1,022 million from the government for other science activities and R&D plant

(including institutional grants such as science development grants, traineeships, bloc grants for construction, and other types of awards that provide for the general support and improvement of scientific capabilities). However, this general institutional funding had dropped dramatically by 1975. While obligations in current dollars for specific R&D projects increased to $2,222 million in 1975, institutional funding for other science activities and R&D plant dropped to $567 million. Such institutional funds comprised 44 percent of the total academic science obligations in 1967 but only 20 percent in 1975. Obligations for R&D plant alone fell from $111 million in 1967 to $45 million in 1975.[28]

This substantial decline in institutional funding means that universities have at their disposal less discretionary money to fill in gaps, start new exploratory studies (conducted prior to project support), and meet other special and changing needs. The reduction or disappearance of these funds also signaled an important change in the top-level federal government concept of the relations between government and universities. Ever since the post-World War II expansion of R&D, federal funds have been used either to buy research needed by government or to support research planned by the grantee. But there was also a vague and somewhat ambivalent high-level acceptance of a federal obligation to help sustain the general health of research universities. In 1954, for example, President Eisenhower issued Executive Order 10521, which assigned to NSF the responsibility for supporting "general purpose" basic research, encouraging each mission agency to support basic research in its specific areas. In addition, 10521 instructed the director of NSF, in cooperation with the U.S. Commissioner of Education, to study the effects of government grants and contract policies on universities, to ensure the realization of government objectives "while safeguarding the strength and independence of the nation's institutions of learning."[29]

When President Kennedy took office, he asked David E. Bell, the new director of the Bureau of the Budget, to serve as chairman of a task review set up to examine policies toward contracting for R&D. The task force reported that

> ...it is our fundamental conclusion that it is in the national interest for the Government to continue to rely heavily on contracts with non-Federal institutions to accomplish scientific and technical work needed for public purposes. A partnership among public and private agencies is the best way in our society to enlist the Nation's resources and achieve the most rapid progress.... With respect to universities, Government agencies share responsibility for seeing that research and development financed at universities does not weaken these institutions or distort their functions which are so vital to the national interest.[30]

In 1965, President Johnson stated in a memorandum to department and agency heads that "research supported to further missions should

be administered not only with a view to producing specific results, but also with a view to strengthening academic institutions and increasing the number of institutions capable of performing research of high quality."[31]

There has been no firm statement of responsibility for the general health of universities from the White House since 1965, although some working-level committees accepted a continuing federal obligation.[32] Specific funding agencies have continually assumed responsibility for the health of sections of the university community (for example, NIH and the medical schools). However, in 1976 Congress enacted a measure, signed into law by President Ford on May 11, 1976, creating a new White House Office of Science and Technology Policy, reflecting a heightened interest in science affairs and the nation's resources for research. The act instructs the President's Committee on Science and Technology to consider "ways to strengthen the nation's academic institutions' capabilities for research and education in science and technology."[33]

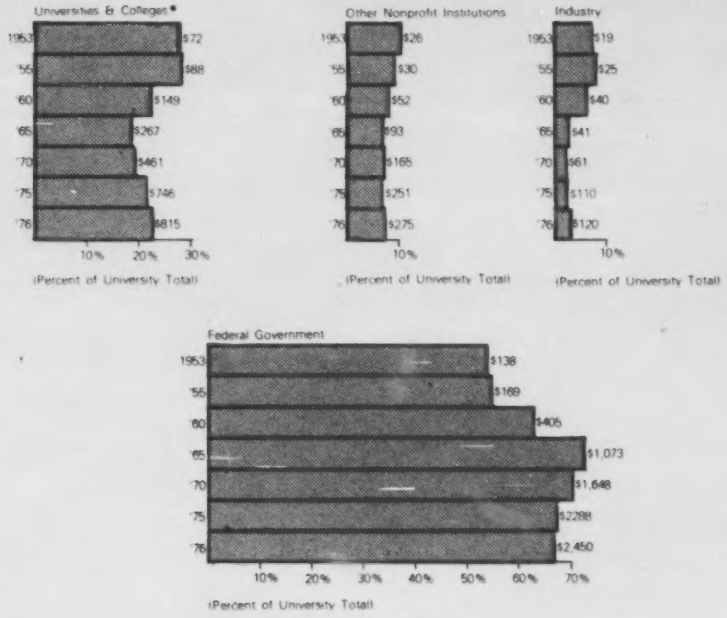
Changing Sources of University Research Support

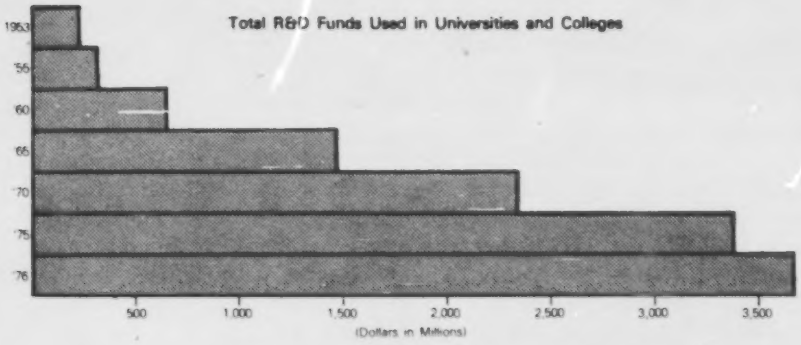
There have been significant changes in the pattern of support received by universities from different sources. First, as Figure 5 illustrates, the federal government's share of support for academic R&D has decreased from a peak in 1965, while the universities' own expenditures (including unrestricted state funds) have increased. This shift reflects a movement back toward the pattern prevailing in the pre-Sputnik days, though the federal share today is still considerably higher than it was at that time.

Although it is apparent that state funding for R&D is greater than in the past, it is difficult to disentangle federal from state funds. There have been notable increases in federal R&D support to state and local government agencies—totaling $228 million in 1975—particularly in such civilian R&D areas as transportation, economic development, criminal justice, and air and water pollution control. The bulk of these funds are then awarded to other research performers, including universities, but the precise distribution of such funds remains undocumented. D.C. Spriestersbach, vice president for educational development and research at the University of Iowa, reported that for 10 selected universities, state funds for sponsored research increased 65 percent between 1970 and 1973.[34] Although this sample undoubtedly reflects an unusually rapid increase, the states' role as a conduit for federal funds could grow in importance. State governments, however, have generally played their most important role as providers of general support for university research (salaries, physical plant, etc.). Only to a very limited extent have states also been direct supporters of research.

Figure 5

Funds Expended Annually for R&D in Universities and Colleges Distributed by Source, Selected Years, 1953-1976 (Percent of University Total and Total Funds)





*Institution's own funds exclude departmental research. Only separately budgeted R&D funds are included. See original source for more detailed explanation of the data.

Source: National Science Foundation, *National Patterns of R&D Resources, 1953-1976*, NSF 76-310, Table B-1, pp. 20-21. Figures for 1975 and 1976 in the original table are estimates.

There have also been important shifts among the federal agencies supporting university research, most notably a decline in the Department of Defense share and an increase in those of HEW and NSF (see Figure 6).

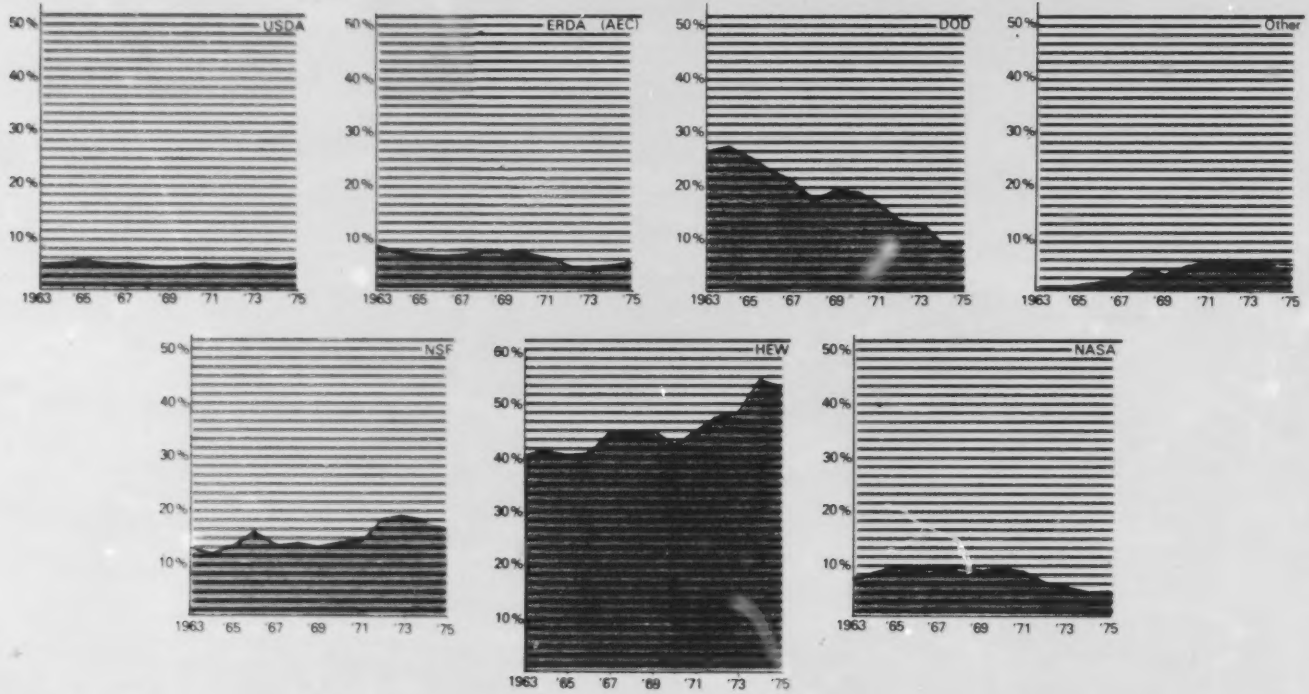
Before the passage of the National Science Foundation Act in 1950, the Office of Naval Research had contracted with over 200 universities to conduct some 1,200 research projects—a volume of work that involved 3,000 scientists and 2,500 graduate students.[35] By the early 1960s, DOD was providing more than one quarter of all federal R&D funds for universities. Since then, its relative share of funding has dropped to less than 10 percent. Meanwhile, those of HEW and NSF have grown. As of 1975, for instance, HEW had provided more than half of all federal funds allotted to university research and NSF nearly one fifth. In more recent years federal priorities for R&D have changed. New agencies have emerged, such as the Department of Transportation and the Department of Housing and Urban Development. Yet these programs still account for only a small percentage of the federally funded research in colleges and universities.

The system of support in the U.S. for academic research has often been described as pluralistic. Within large agencies such as Defense or HEW there are several more or less independent programs, all making grants or contracts for university research. Yet one agency—HEW—provides over half of all the federal dollars going to universities for research; two agencies account for almost three quarters of the total; and five agencies provide more than 90 percent. These, as well as the smaller agencies, naturally tend to work within their own spheres of interest and therefore tend to support only certain types of research.

The degree of pluralism in research support has declined, and investigators have fewer potential sponsors for their fields of inquiry. For example, several years ago NIH phased out its research support in photosynthesis. Some fields, such as pure mathematics, have become essentially dependent upon a single sponsoring agency—NSF—whereas 10 years ago other potential sponsors were available.[36] This new sorting out of research missions, with agencies maintaining clearer responsibilities for particular areas of research support, has sometimes had beneficial effects, creating in the sponsoring agencies a fuller sense of responsibility for the long-term vitality of their particular fields. But the adverse affect of dependence on the judgments and decisions of a smaller number of persons and the availability of fewer points of access for support cannot be ignored. And there is always the fact that HEW has become so much the dominant agency that changes in its policies, priorities, regulations, and procedures are of very special concern to the universities.[37]

Figure 6

Federal Obligations for R&D to Universities and Colleges As a Percentage of Total, by Agency, FY 1963-1975



Source: National Science Foundation, *Federal Support to Universities and Colleges and Selected Nonprofit Institutions, FY 1974,* NSF 75-325, Detailed Statistical Tables, Appendix B, p. 1. Figures for 1975 in press.

The Shift to Support of the Life Sciences

One development related to the shift in agency funding is a corresponding shift in the funding of different science fields. Because the research support by DOD, ERDA, and NASA has proportionately decreased and that of HEW and NSF has increased, federal sponsorship has shifted from physical science and other related fields to the life sciences. In the period 1971-75, as shown in Figure 7, government funding in the physical sciences dropped from 17 to less than 14 percent of all federal R&D obligations to colleges and universities. Physics alone experienced a 40 percent drop in its share. Moreover, chemistry and engineering received slightly lower proportionate amounts over the period. (The field of physics experienced a slight absolute decline as well as a decrease in its proportionate share of federal R&D obligations.)

In contrast, the proportionate amount of federal dollars for support of life sciences research rose from 48 percent in 1971 to 54 percent in 1975. Because of the larger base of support, the change reflects a two-thirds increase in a brief period, stimulated by heightened national emphasis on cancer research. This funding trend has also promoted some shifts of emphasis within the disciplines. For example, substantial research funds in the field of chemistry have been allocated to biochemistry—the branch most closely related to health and medicine—and to other fields that have potential biomedical applications.[38]

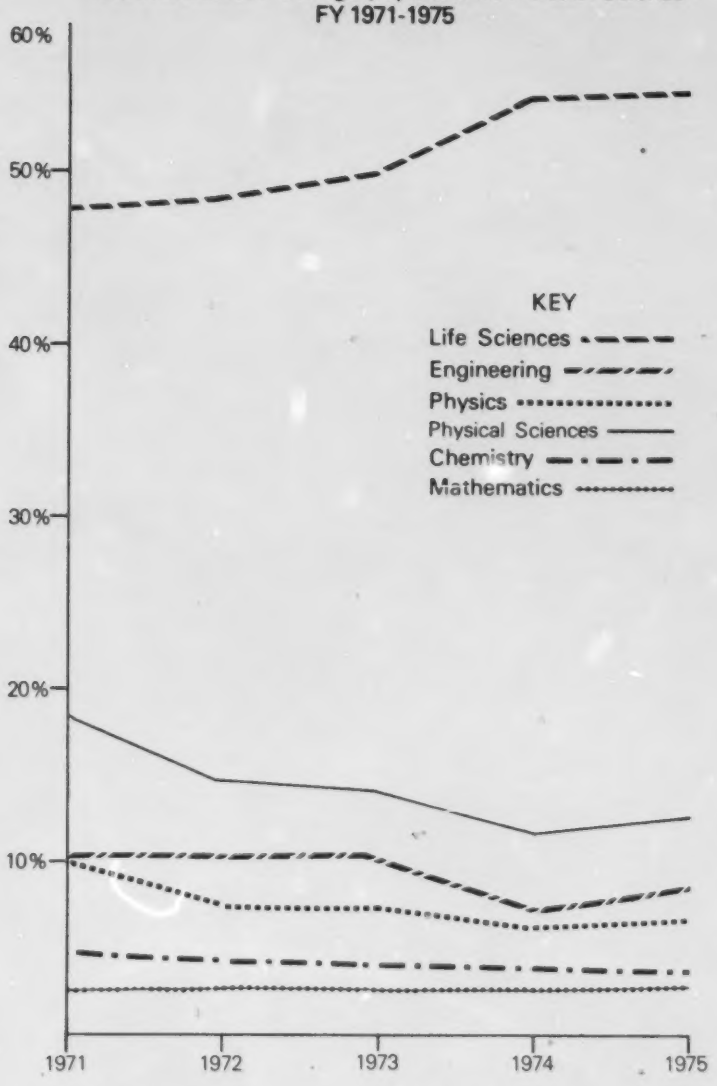
Increased Emphasis on Targeted and Applied Research

Another recent significant trend has been the increased federal support of "targeted" research, that is, research with specific, definable objectives. The trend is difficult to document precisely. But the practice of more detailed definitions of research objectives and procedures, the increased use of contracts rather than grants, and the tailoring of research support more closely to specific agency missions are apparent on the part of many funding agencies.

The point is conveyed, but only imperfectly, by saying that there has been increased emphasis on applied as opposed to basic research. The distinctions between basic and applied research are often hazy, and in many cases it makes little difference whether a research project is formally classified as basic or applied. At times a university has used one label while the funding agency has used the other for the same project. Often it is impossible to tell from the name of an agency or a program whether the research supported will have a basic or an applied character. The Department of Defense long supported fundamental scientific work, although directed at very practical ends, and funds for the

Figure 7

Proportional Distribution of Federal Obligations for R&D in Universities and Colleges, by Selected Fields of Science FY 1971-1975



Source: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, 1970-1974*, Annual Publications. (1975 in press.)

targeted national cancer program have also been used for basic research in the biological and life sciences.

The newer agencies, such as the Department of Transportation, which provide only a small share of research funding, are essentially interested in applied research. But even established agencies, including HEW and NSF, have shifted emphasis to some extent to applied and targeted research as well. From 1967 to 1974, all of the major funding agencies supporting university research (except for NASA, which experienced budget cutbacks) decreased the percentage of their funds allocated to basic research: in HEW from 32 to 25 percent; in NSF from 91 to 79 percent.[39]

In 1966 President Johnson, speaking to medical and hospital leaders on Medicare, expressed the new emphasis on applied research:

> A great deal of basic research has been done. I have been participating in the appropriations for years in this field. But I think the time has now come to zero in on the targets by trying to get our knowledge fully applied.... Now Presidents, in my judgment, need to show more interest in what the specific results of medical research are during their lifetimes and during their administrations. I am going to show an interest in the results.
>
> I would hope that for whatever time I have in the White House, about every six months we could come back and see what progress we are making. Because these men are now responsible for over a billion dollars of research and training money, I want them to be sure that they have the best defined programs and goals in this country.[40]

The establishment of RANN (Research Applied to National Needs) within NSF is another development in applied research sponsorship. In 1968, the Foundation was "authorized to initiate and support scientific research, including applied research, at academic and other nonprofit institutions." Moreover, NSF was empowered, when requested by the President, "to support, through other appropriate organizations, applied scientific research relevant to national problems involving the public interest."[41]

In response to this mandate, NSF established the IRRPOS program (Interdisciplinary Research Relevant to the Problems of Society), later expanded to become the RANN effort, which in 1972 received 8.6 percent of the NSF budget. The RANN portion of the NSF budget rose to 13 percent in 1974 but dropped to 10 percent in 1976.[42] NSF has been least affected by the shifting emphasis toward applied fields among the federal agencies sponsoring university research. (The earlier cited decline in NSF support of basic research from 91 to 79 percent of its budget is accounted for in considerable part by the establishment of the RANN program.)

The Mansfield Amendment was an action of considerable significance in reflecting and giving further impetus to the mood favoring a shift in

the balance between investigator-initiated and agency-directed research efforts in the universities. The Mansfield Amendment (Section 203 of Public Law 91-121, the Military Procurement Authorization Act of 1970) specified that "none of the funds authorized to be appropriated by this act may be used to carry out any research project or study unless such project or study has a direct and apparent relationship to a specific military function or operation." The Amendment had the immediate effect of shifting some programs from DOD to NSF sponsorship, though not always with the same level of support.

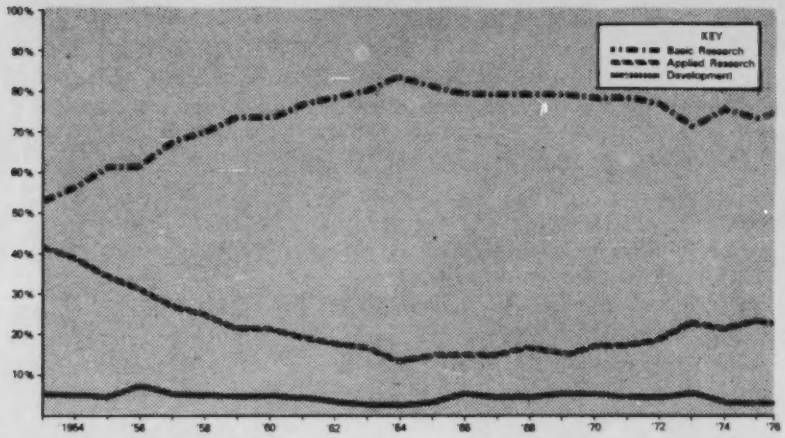
Although the Amendment is no longer in effect, it illustrates the mission agencies' tendencies to define strictly the kinds of research relevant to their tasks. Concern over the impact of the Mansfield Amendment was a contributing factor in the appeal issued by the National Science Board to the mission agencies in 1974 to take a broad view of their needs for mission-oriented basic research.[43] Nichols's assessment remains pertinent: "The Mansfield Amendment is important not because its direct effects have been great, but because it is the formal expression of deeper congressional concerns, the tip of an apparently large iceberg—and it does have the stamp of the majority leader of the Senate."[44]

The increased emphasis on applied research, shown in Figure 8, has had its influence on university researchers: Many of them have had to shift fields. As indicated earlier, a number of faculty members changed fields of research in the period from 1968 to 1975 due to lack of support in their primary fields.[45] In 84 percent of the cases, a move was made because better chances for support were expected, because the change was suggested by the funding organization, or because the funding organization emphasized applied rather than basic research.[46] Such changes were of course intended by the federal officials who had shifted priorities in accordance with their sense of national needs. However, in those university departments rated "distinguished" or "strong" in the Roose-Andersen ratings (1970) conditions were seen as more favorable to individual research interests: 91 percent of the faculty members in those departments were spending 20 percent or more of their time in research; 72 percent were receiving federal support; and 64 percent were generally able to secure support for research in areas of their own choosing.[47] (Similar to the 1964 effort by Allan Cartter to rate the quality of graduate departments across a variety of fields, the 1970 Roose-Andersen ratings are based on a peer review survey of graduate departments carried out by Kenneth Roose and Charles Andersen under the auspices of the American Council on Education. The Roose-Andersen ratings are used throughout this study, in particular in Chapter IV.)

It is difficult to make broad generalizations about the overall impact of the shift in emphasis upon the universities. No clear single pattern emerged from our site visits; the most striking impression is that of the

Figure 8

Proportional Distribution of Federal Funds Expended Annually by Universities for Basic Research, Applied Research, and Development, FY 1953-1976



Source: National Science Foundation, *National Patterns of R&D Resources, 1953-1976*, NSF 76-310, Tables B-1, B-2, B-3, B-4, pp. 22-27.

diversity of experience and perception among different fields and types of institutions.

How far apart universities can be with respect to their attitudes toward applied research was well illustrated in the very divergent comments of the academic vice presidents of two institutions:

> Vice President of Institution A: "This university is willing to do almost anything of benefit to the state."
>
> Vice President of Institution B: "The very brightest people are found at universities like this one; they should do the kind of fundamental work that only they can do, and that eventually will help everyone else."

The increased emphasis on research targeted on current problems is acceptable—indeed enthusiastically welcomed—by the first university vice president, but the attitudes of the vice president in the second institution are much more ambivalent and, in general, less receptive to targeted research.

For most universities there is a much less well-articulated attitude marked by uncertainty. The question of how universities should respond, if at all, to pressures for greater relevance in research is on the agenda. Positions have yet to crystallize, but a few general observa-

tions can be made: First, there are conflicts in many of the institutions attempting to expand applied programs while maintaining their traditions of basic research; many faculty members insist that the university is ill adapted for applied research. Second, there is no indication that any university, or any group of universities, is willing to be excluded altogether from applied research. But even the most applications-oriented universities strive to maintain basic research. Overall, the degree of specialization among universities has grown, with a number of institutions and departments increasingly in search of distinctive areas of research competence.

Third, there is growing concern that the balance may have swung too far toward agency-directed efforts and away from investigator-initiated projects. One department chairman, generally sympathetic to targeted research, expressed his concern in these characteristic terms: "You may want a cancer cure; that's fine, but you have to let the scientist tell you how to get there."

The President's Panel on Biomedical Research, reviewing the 1967-75 increase from 12 percent to 26 percent of the NIH budget devoted to R&D contracts, echoed similar concerns:

> Although the dollars spent for traditional research grants have increased...the percentage of extramural funds spent for such research grants between fiscal years 1967 and 1974 has declined from about 60 percent to about 45 percent. The Panel is concerned about this trend away from this highly respected and enormously productive instrument of support. The investigator-initiated research grant has been the primary instrument without which major advances in improving the nation's health would not have been possible.
>
> The Panel believes that when it is desirable for an Institute to emphasize a particular area of research because of unusual scientific opportunities, the grant is still the best mechanism of support.... The Panel therefore recommends that the grant continue to be the predominant vehicle for the support of research and that investigator-initiated, peer-reviewed, grant-supported, fundamental science should continue to be a substantial component of the research programs of the NIH and the ADAMHA [Alcohol, Drug Abuse, and Mental Health Administration].[48]

Finally, the emphasis on targeting may also be part of a larger tendency toward "playing it safe," toward conservatism in funding practices. Many researchers expressed the view that research proposals by established investigators, within established lines of inquiry and promising short-run and politically defensible returns, were receiving increased emphasis at the expense of more innovative proposals. The evidence on such points is field dependent and influenced by many institutional and departmental factors. Further discussion of this issue is contained in Chapter IV.

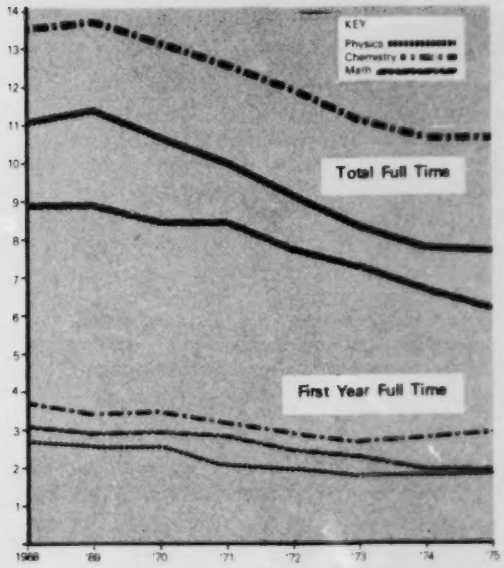
Graduate Enrollment Trends

In addition to its direct link with current research efforts, graduate education is also essential to the long-run health of academic science. Since 1968, graduate enrollments in many (but by no means all) fields of science and engineering have declined, recovering slightly only in the past few years. Enrollment trends in physics, chemistry, and mathematics from 1968 to 1975 are shown in Figure 9. In that period total full-time enrollments in physics declined by 30 percent, in chemistry by 21 percent, and in mathematics by 31 percent. First-year enrollments also dropped substantially until 1973; they have risen slightly since then in physics and chemistry.

This drop in graduate enrollments has also led to a drop in PhD production. Figure 10 charts the number of PhD degrees awarded nationally in the three fields in the period 1960-75 and reflects enrollment de-

Figure 9

First-Year and Full-Time Graduate Enrollments in Matched Physics, Chemistry, and Mathematics Departments FY 1968-1975*



*The data, derived from the NSF Survey of Graduate Science Student Support and Postdoctorals, encompass 168 chemistry departments, 146 physics departments, and 120 mathematics departments, covering more than 90 percent of the departments in each discipline included in the Roose-Andersen survey. The data cover 122 of 124 rated chemistry departments, 109 of 113 rated physics departments, and 93 of 102 rated mathematics departments. The numbers of nonrated departments included in the data are 46 chemistry, 37 physics, and 27 mathematics departments.

Source: David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).

Table 2

Percentage of Total Full-Time Graduate Enrollment in Highest Rated Physics, Chemistry, and Mathematics Departments, FY 1968-1975*

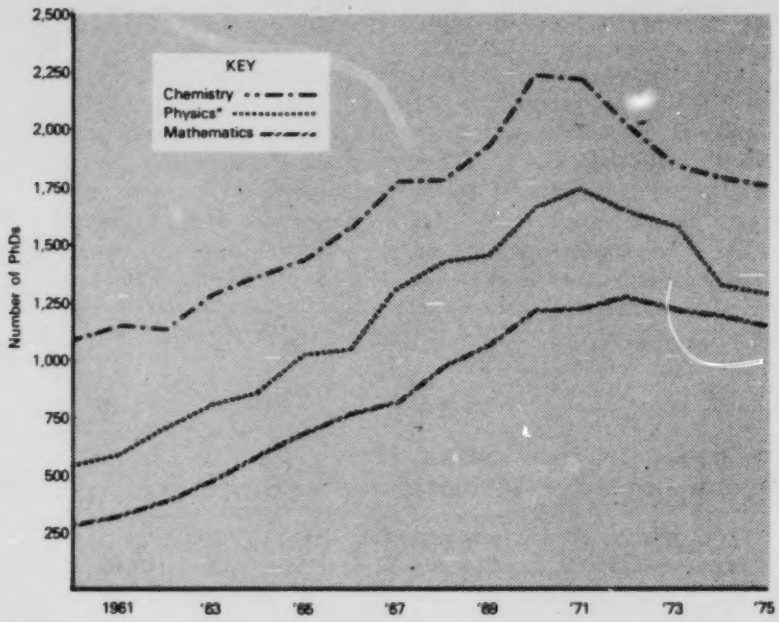
Year	1968	1969	1970	1971	1972	1973	1974	1975
Physics	19.1	18.4	18.7	18.5	18.4	19.1	20.3	20.8
Chemistry	17.4	17.3	17.5	17.1	16.8	17.1	17.7	18.1
Mathematics	13.6	13.0	12.9	13.4	13.4	14.8	15.3	15.9

*Departments rated 4.0-5.0. See Kenneth D. Roose and Charles J. Andersen. *A Rating of Graduate Programs.* Washington, D.C.: American Council on Education, 1970.

Source: David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).

Figure 10

Annual Production of Chemistry, Physics, and Mathematics Doctorates, FY 1960-1975



*Includes astronomy.

Source: National Academy of Sciences, *Doctorate Recipients From United States Universities, 1958-1966* (Washington, D.C.: National Academy of Sciences, 1967), p. 5. *Doctorate Recipients From United States Universities, 1967-1970*, Annual Publications.

clines beginning in the late 1960s. PhD production peaked in chemistry in 1970, in physics in 1971, and in mathematics in 1972. The fact that these enrollment declines have continued well into the 1970s indicates that total PhD output will continue to fall until at least 1980.[49] Table 2 shows that the very highly rated or "distinguished" departments (4.0-5.0 on the Roose-Andersen scale) in physics, chemistry, and mathematics have slightly increased their shares of total enrollment over the eight-year period.

The data conceal differences in the size of departments by quality category. Although full-time enrollments have declined in absolute numbers in each quality grouping over the eight years, it should be noted that the highest rated departments remain four to six times larger, on average, than the lowest rated departments.[50] Some of the lowest rated departments have reached (or are approaching) an enrollment level so low that continuation of the doctoral programs may be in question. In fact, in some states doctoral programs have been formally closed. New York State has closed five (and 22 have been voluntarily withdrawn after the initiation of a doctoral review program by the state's education department). Elsewhere programs have been "suspended" (become inactive without a formal abandonment). In other cases, departments have awarded as few as one or two PhDs per year. Some small doctoral programs, however, remain in vigorous condition, serving special regional or occupational manpower markets and maintaining active research programs.

The impact of enrollment declines on actual research efforts, in general, has been less severe than expected. Many departments have adjusted readily to the changes, and their research efforts have been relatively unaffected. The enrollment declines have tended to affect the research activities of those departments that instituted PhD programs relatively recently. A special problem exists in the case of public universities with large undergraduate enrollments, which are heavily dependent on graduate students in the instructional process; declining graduate enrollments have meant that senior faculty teaching loads have increased (further discussions of this point are found in Chapters IV and V).

Institutional Concentration of Federal Funds for Academic Research

Most of the federal funds for academic research are concentrated in universities as opposed to other kinds of educational institutions, and within that group the major research universities receive the largest share. Each year, 100 universities account for more than 85 percent of all academic research expenditures (see Table 3). This heavy concentration in a relatively small number of universities can be attributed to

Table 3

Proportional Concentration of R&D Funds Among Universities, Selected FY 1963-1975

Year	Top 10	Top 20	Top 50	Top 100
1963	32.8%	49.5%	71.9%	89.5%
1967	29.1	44.9	69.6	88.1
1968	27.7	43.1	67.4	86.7
1969	27.4	43.2	67.3	86.1
1970	27.8	43.3	67.6	86.1
1971	27.1	42.7	67.2	85.8
1972	27.4	42.8	67.0	85.3
1973	27.1	42.4	67.1	85.1
1974	27.3*	42.8	67.2	85.7
1975	25.8*	41.4	66.2	85.0

* Includes funding for Draper Laboratories. Funding for the Draper Laboratories—because of a change in its charter to an independent nonprofit corporation—was reported separately from MIT funding for the first time in 1974 and 1975. Another change in reporting procedures should also be noted. At multicampus systems, the reporting unit has sometimes changed. In some cases the research statistics of the entire system have for a time been attributed to a single campus. Thus changes in reporting procedures can alter an institution's relative standing. Such reporting changes can complicate time series analysis of research statistics, and reported data should therefore be viewed with care.

Source: National Science Foundation. *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions.* Annual Publications (1975 data in press).

Table 4

Universities Gaining as Recipients of Federal Reseach Funds, 1964 and 1974

Institutions	Ranking 1964	1974
University of California, San Diego	37	5
Washington University	28	18
University of California, San Francisco	36	19
University of Alabama, Birmingham	80	40
University of Hawaii	71	41
City University of New York—Mt. Sinai School of Medicine	*	44
Colorado State University	68	45
Boston University	83	50

*Not in top 100 in 1964.

Source: General Accounting Office. *Geographical Distribution of Federal Science Funds to Colleges and Universities.* Washington, D.C.: GAO Report B-117219, 1976, p. 11.

Table 5

R&D Expenditures of 20 Largest Universities as a Percent of Total R&D Expenditures by Field, With Three Definitions of "the 20 largest," 1970 and 1974

	Engineering		Physical Sciences		Mathematics		Life Sciences		Social Sciences		Environmental Sciences		Psychology	
	'70	'74	'70	'74	'70	'74	'70	'74	'70	'74	'70	'74	'70	'74
Largest 20 universities in '70; same 20 in '74	41%	45%	45%	41%	39%	36%	31%	33%	46%	38%	30%	45%	36%	37%
Largest 20 in each field in '70; same 20 in '74	46	52	50	41	49	46	32	35	52	35	38	32	35	37
Largest 20 in each field in '70; largest 20 in '74	46	44	50	47	49	56	32	37	46	43	38	63	35	51

Source: National Science Foundation. *Expenditures for Scientific and Engineering Activities at Universities and Colleges.* Annual Publications.

several factors: Four-year colleges, and to a greater extent community colleges, are primarily concerned with teaching. Universities, on the other hand, consider research an essential function, and they recruit faculty committed to research. NSF and other government agencies and private foundations, despite the criticisms of the peer review system and proposals for geographic distribution formulas, still base their grant decisions on merit and the desire to use their funds as productively as possible. This has led them to the universities where the best scientists and research facilities are to be found.

In the past decade there has been a slight decline in the concentration of federal research funds in the universities. Further, there have been substantial shifts, as some institutions have dramatically increased their research funds while others have fallen back. Early in the 1960s, as Table 3 shows, a full third of all federal funds allocated to academic research went to only 10 universities. Concentration at the top is still the case, but the share has gradually declined. The top 20 universities, which received half the total a dozen years ago, now get about 40 percent. The top 100, which had 90 percent of the total, now get 85 percent. Some of the universities in the top 100 recipients that have made dramatic gains in funds are listed in Table 4.

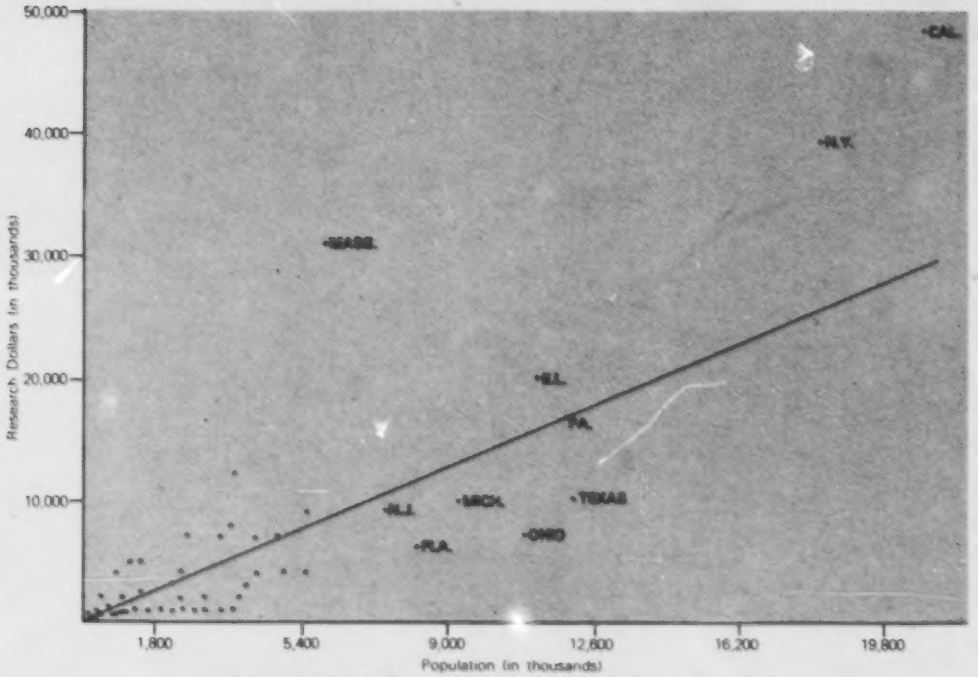
Dael Wolfle, in his background paper for this project, identified 17 universities whose shares of federal R&D funds increased by 25 percent or more from 1963-65 (a three-year average) to 1973-75, and an additional three universities whose shares increased between 15 and 24 percent over the same period.[51] Of course, the matter becomes more complicated when an attempt is made to chart changes by broad fields of science within the overall institutional totals. Table 5, which includes three definitions of the "20 largest," illustrates the complexities in interpreting the results of such an exercise. The data are affected by changes in funding within fields as well as overall changes in an institution's place on the list of recipients of federal funds. They confirm the picture of relative institutional concentration of funding but with considerable movement in relative positions on the list.

The geographical distribution of federal research funds remains concentrated as well. Yet in the past decade those regions with smaller shares of federal funds generally showed the largest rate of growth: the East South Central increasing 129 percent between 1963 and 1974; the West South Central, 105 percent; the South Atlantic, 102 percent; and the Mountain region, 101 percent.[52]

When research funds are plotted against state populations, as in Figure 11, it is apparent that most states receive proportions roughly corresponding to their populations, while only a few states receive much larger amounts. A rather different picture emerges if regional funding is plotted against rough measures of scientific quality. For example, in the distribution of research funds to states based on the number of members of the National Academy of Sciences and the National Acad-

Figure 11

Scientific Research Project Support Dollars for Each State Plotted Against State Populations, 1974



Source: National Science Foundation, Atkinson, p. Z71. See footnote 53.

emy of Engineering, some of the more populous states appear to be relatively disadvantaged. The states that seemingly do well in terms of population alone do less well than might be expected if judged by various criteria of merit. Results similar to the latter are obtained if one measures dollars to each state against publications in leading scientific journals. There are many ways in which to argue the issue, but the fundamental conclusion is the absence of severe geographical imbalances in the distribution of funds by most accepted measures.[53]

Site visits reveal considerable parochialism within universities about such questions as geographical distribution of research funds. Complaints at the elite universities ("It's an outrage; because of politics they are sending all that money to awful places where it will be wasted") complement the litany occasionally heard at less prestigious universities ("You can be sure the big boys won't leave much—even a superb proposal from our department doesn't have much of a chance"). Despite such complaints, the evidence does not suggest any striking regional imbalances.

Summary

This chapter has presented a largely statistical portrait of the major trends affecting the universities as research performers. The funding of academic research, which grew rapidly in the postwar period, has tended to level off in recent years, no longer exhibiting rapid growth but remaining at substantial levels. Among other trends, universities have been affected by pressures for greater "targeting" in funding practices, by declining graduate enrollments in some fields, and by shifts toward greater support for the life sciences area, especially fields closely linked to medicine. The remaining chapters focus on specific areas of these recent trends and seek to assess the implications of recent developments for the future role of the universities in the nation's research effort. Chapter III begins this assessment with a discussion of the changing relationships between universities and other R&D performers.

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1. National Academy of Sciences, Committee on Science and Public Policy, *Federal Support of Basic Research in Institutions of Higher Learning* (Washington, D.C.: National Academy of Sciences, 1964), p. 16. See, generally, A. Hunter Dupree, *Science in the Federal Government: A History of Policies and Activities to 1940* (Cambridge, Mass.: Harvard University Press, 1957); Charles V. Kidd, *American Universities and Federal Research* (Cambridge, Mass.: Belknap Press of Harvard University Press, 1959); Don K. Price, *Government and Science: Their Dynamic Relation in American Democracy* (New York: New York University Press, 1954); and Dael Wolfle, *The Home of Science: The Role of the University* (New York: McGraw-Hill, 1972).

2. National Academy of Sciences, *Federal Support*, op. cit., p. 17.

3. A. Hunter Dupree, *Science in the Federal Government: A History of Policies and Activities to 1940* (Cambridge, Mass.: Belknap Press of Harvard University Press, 1957), pp. 1-2.

4. Lewis E. Auerbach, "Scientists in the New Deal: A Pre-War Episode in the Relations Between Science and Government in the United States," *Minerva* 3 (Winter 1965), pp. 457-482.

5. The NDRC was chartered to "correlate and support scientific research on the mechanisms and devicee of warfare" and the broadened OSRD mandate was to "serve as the center for mobilization of the scientific personnel and resources of the Nation in order to assure maximum utilization of such personnel and resources in developing and applying the results of scientific research to defense purposes." James Phinney Baxter, *Scientists Against Time* (Boston: Little, Brown and Company, 1946), p. 451. Irwin Stewart, *Organizing Scientific Research for War: The Administrative History of the Office of Scientific Research and Development* (Boston: Little, Brown and Company, 1948), pp. 335-336.

6. National Academy of Sciences, *Federal Support*, op. cit., pp. 24-27.

7. Vannevar Bush, *Science—The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research*, July 1945 (Washington, D.C.: National Science Foundation, reprinted July 1960), p. 3.

8. Ibid., p. 8.

9. National Academy of Sciences, *Federal Support*, op. cit., p. 31.

10. John R. Steelman, *Science and Public Policy: A Program for the Nation*, Vol. I (Washington, D.C.: U.S. Government Printing Office, 1947), p. 6.

11. Research data for 1976 used in this study are based on official NSF estimates.

12. Between 1968 and 1976, total national expenditures on R&D decreased by 5 percent in constant dollars. However, total national expenditures on basic research decreased by 11 percent in constant dollars over the same period. See *National Patterns of R&D Resources, Funds and Manpower in the United States, 1953-1976*, NSF 76-310, Tables B-5, B-6 (Washington, D.C.: National Science Foundation), pp. 28-29.

13. Ibid., Table B-6, p. 29. Depending on which data series is used and the time periods considered, different percentage declines in constant dollar basic research support can be obtained. Expenditure data is based on the amount of funds actually spent in a given year, while obligations data is comprised of commitments to spend money (contracts, grants, etc.) in which the actual expenditure of funds may take place over a period of several years. The 15 percent drop in real basic research support quoted in the text is based on expenditure data. However, using the GNP implicit price deflator, an estimated 19 percent decline between 1967 and 1976 can be calculated on the basis of obligations data. For current dollar obligations data, see *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years 1975, 1976 and 1977*, Vol. XXV, Detailed Statistical Tables, Appendices C and D, NSF 76-315, Table C-118 (Washington, D.C.: National Science Foundation), p. 147.

14. Current dollar amounts are taken from National Science Foundation, *National Patterns of R&D Resources*, op. cit., Table B-2, p. 23. The GNP implicit price deflator has been used to calculate constant 1972 dollars.

15. Willis H. Shapley, *Research and Development in the Federal Budget, FY 1977*, Report No. 76-R-4 (Washington, D.C.: American Association for the Advancement of Science, May 1976), pp. 130-131. For an excellent discussion of R&D budget data, see pp. 33-64. On the difference between obligations and expenditures, see p. 41.

16. National Science Board, *Science Indicators—1974: Report of the National Science Board, 1975* (Washington, D.C.: National Science Foundation, 1975), Table 3-12, p. 198. For a further discussion of how the tighter funding environment has actually affected university researchers in various fields, see Chapter IV.

17. The figures are derived from NSF statistics, principally *National Patterns of R&D Resources*, op. cit. The principal differences between these figures and those reported in the NSF annual series *Federal Funds for Research, Development, and Other Scientific Activities* are: (1) They are based on actual expenditures of federal funds reported by the R&D performers rather than on obligations reported by the federal funding agencies (except for federal intramural laboratories, where obligations are used in both series). The performers' expenditure data differ from agency obligations both in timing and divisions among basic research, applied research, and development categories. (2) *National Patterns* combines calendar year data for universities and federal intramural laboratories, while *Federal Funds* uses fiscal year data for all performers.

18. NSF, *National Patterns*, op. cit., Table B-2, pp. 22-23.

19. David Z. Robinson, "Will the University Decline as the Center for Scientific Research?" *Daedalus* 102 (Spring 1973), pp. 109-110.

20. NSF, *National Patterns*, op. cit., Table B-1, pp. 20-21.

21. The data in Table 1 are taken from the National Science Foundation, *Federal Funds for Research, Development, and Other Scientific Activities*, op. cit., Vol. XVI (1967), pp. 112-113; Detailed Statistical Tables (1976), pp. 16-17. The performer share totals are not the same as those shown in Figure 3 because of the different data series used. See footnote 13.

22. *Physics Today*, September 1976, pp. 77-78.

23. For further data on the increased emphasis on civilian R&D, see National Science Board, *Science Indicators*, op. cit., pp. 40-43. See also *An Analysis of Federal R&D Funding by Function, Fiscal Years 1969-1976*, NSF 75-330 (Washington, D.C.: National Science Foundation). For more current data see *An Analysis of Federal R&D Funding by Function, Fiscal Years 1969-1977*, NSF 76-325 (in press).

24. *Young and Senior Science and Engineering Faculty, 1974: Support, Research Participation, and Tenure*, NSF 75-302 (Washington, D.C.: National Science Foundation, 1975), p. 4. Frank J. Atelsek and Irene L. Gomberg, *Faculty Research: Level of Activity and Choice of Area*, Higher Education Panel Report, No. 29 (Washington, D.C.: American Council on Education, 1976), Table 1A, p. 12.

25. National Science Foundation, *Young and Senior Science and Engineering Faculty, 1974*, op. cit., Table B-36, p. 37.

26. Ibid., p. 9.

27. Frank J. Atelsek and Irene L. Gomberg, op. cit., Table 4-A, p. 15.

28. *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year 1974*, NSF 75-325, Detailed Statistical Tables, Appendix B (Washington, D.C.: National Science Foundation, 1975), Table B-1, pp. 1-2. (1975 data in press.)

29. Dael Wolfle, *The Home of Science: The Role of the University* (New York: McGraw-Hill, 1972), p. 125.

30. Report to the President, April 30, 1962 (The Bell Report), quoted in U.S. Congress, House Committee on Government Operations, *Hearings Before the Subcommittee on Government Operations*, Part I, Eighty-seventh Congress, Second Session, 1962, pp. 192, 233. The task force went on to state, after the last quoted point, its belief in the desirability of some institutional funding to universities, while thinking that "it would not, in our judgment, be desirable to place major reliance on the institutional grant, since the major purpose of making grants in most cases is to assure that the university personnel and facilities concerned will be devoted to pursuing a specific course of inquiry."

31. Dael Wolfle, op. cit., p. 118.

32. Federal Interagency Committee on Education, *Federal Policy and Graduate Education* (Washington, D.C.: Department of Health, Education, and Welfare, June 1975).

33. Public Law 94-282. See *United States Code Service*, Lawyers Edition, Issue No. 6. (Rochester, N.Y.: Ninety-fourth Congress, Second Session, June 1976), p. 1586.

34. D.C. Spriestersbach, Margery E. Hoppin, and John McCrone, "University Research and the New Federalism," *Science*, October 25, 1974, p. 324. The state share of academic funding of medical centers also increased substantially in the past decade, growing from 13 percent of the total operation budget of academic medical centers in 1965 to 20 percent in 1974. See American Council on Education, Association of American Medical Colleges, and the Rand Corporation, "Impact of Federal Health-Related Research Expenditures Upon Institutions of Higher Education," *Report of the President's Biomedical Research Panel* (Washington, D.C.: U.S. Department of Health, Education, and Welfare, April 30, 1976).

35. Clarence H. Danhof, *Government Contracting and Technical Change* (Washington, D.C.: The Brookings Institution, 1968), p. 56.

36. See discussion on mathematics, Chapter IV.

37. See Chapter V for a discussion of the impact of government regulations on the university research environment.

38. See discussion on chemistry, Chapter IV.

39. National Science Board, *Science Indicators*, op. cit., Table 3-4, p. 188.

40. Lyndon B. Johnson, *Public Papers of the President of the United States, Book I* (Washington, D.C.: U.S. Government Printing Office, 1968), p. 610.

41. U.S. Congress, Senate, Special Subcommittee on Science and the Committee on Labor and Public Welfare, *National Science Foundation Act Amendments of 1968*, Ninetieth Congress, First Session, 1968, pp. 2-5.

42. NSF budget data.

43. U.S. Congress, House, Subcommittee on Science, Research and Technology of the Committee on Science and Technology, *1976 National Science Foundation Authorization*, Ninety-fourth Congress, First Session, 1975, pp. 28-29.

44. Rodney W. Nichols, "Mission-Oriented R&D," *Science*, April 2, 1971, p. 29.
45. National Science Foundation, *Young and Senior Science and Engineering Faculty, 1974*, op. cit., p. 9.
46. Frank J. Atelsek and Irene L. Gomberg, op. cit., p. 17.
47. National Science Foundation, *Young and Senior Science and Engineering Faculty, 1974*, op. cit., p. 38.
48. Public Health Service, *Report of the President's Biomedical Research Panel*, DHEW Publication No. (OS) 76-500, (Washington, D.C.: U.S. Department of Health, Education, and Welfare, 1976), p. 17.
49. For a more detailed discussion of the dynamics of PhD production, see Richard B. Freeman and David W. Breneman, *Forecasting the Ph.D. Labor Market: Pitfalls for Policy* (Washington, D.C.: National Academy of Sciences, 1974).
50. For example, in 1975, the highest rated physics departments each had an average of 161 full-time graduate students, while the nonrated departments had an average of only 33; in chemistry, the highest rated departments had an average of 175 students and the nonrated, 29; in mathematics, the highest rated had an average of 123 students and the nonrated, 32. See David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).
51. Dael Wolfle, "Forces Affecting the Research Role of Universities," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977). The institutions also invariably advanced in their place on the ranking of the list of the 100 largest recipients of federal R&D funds. Wolfle identified 10 universities whose shares decreased by 25 percent or more and 11 whose shares decreased from 15 percent to 24 percent over the same period.
52. *Geographical Distribution of Federal Science Funds to Colleges and Universities*, GAO Report No. B-117219, Appendix I (Washington, D.C.: General Accounting Office), p. 6.
53. For a thorough discussion, see the testimony of Dr. Richard C. Atkinson, Deputy Director, National Science Foundation, in *Peer Review Special Oversight Hearings* before the Subcommittee on Science, Research and Technology of the Committee on Science and Technology, U.S. House of Representatives, Ninety-fourth Congress, First Session (Washington, D.C.: Government Printing Office, July 23, 1975), pp. 269-291.

III

The Changing Relationships: Universities and Other R&D Performers

While there has been no fundamental change in the division of labor among the different research performers, both new forms of collaboration and increased competition seem to be emerging between universities and other research sectors. Closer ties between universities and industry are an important development, though obstacles to collaborative effort continue to exist.

There are several mechanisms to encourage closer academic/industrial ties in research. These include direct corporate funding of university research, cooperative or cost sharing research programs, university/industry research consortia, and joint laboratories. Improved knowledge transfer could be achieved through consulting, technology licensing and technology brokering, university industrial associates programs, and the development of additional university-connected industrial parks, innovation centers, and university/business development centers. Although improved university/industry relations could be important, it seems unlikely that industrial support for academic research will become as important as it was before World War II and in the immediate postwar period.

Chapter III

The Changing Relationships: Universities and Other R&D Performers

The United States research system, as outlined in Chapter II, comprises a rich variety of R&D performers, each playing an important role in the overall system. The universities are the principal but not exclusive performers of basic research, while other institutions take primary responsibility for applied research and development. According to the categories defined by the National Science Foundation, these other research performers are: the federal in-house laboratories, federally funded research and development centers (FFRDCs) managed by universities, industrial firms (and FFRDCs managed by industry), and a residual category that includes independent research institutes, hospitals, and state and local government agencies.

Although these performers carry out fairly distinct roles that encourage a division of labor in the system, their functions overlap enough to create a certain amount of competition among them. This competition is usually considered a healthy way of maintaining the system's dynamism, discouraging institutional rigidity, and avoiding undue dependence on any one sector for achieving national R&D goals. As a recent study of federal laboratories concludes: "The quality of the U.S. R&D system depends on keeping creative tension among all performer organizations and maintaining the quality of each sector."[1]

Each research performer's shares of federal R&D funds since 1967 appear in Table 1, which shows universities and federal intramural performers increasing their shares from 1967 to 1976, while industry's share declined.

There is no reason to suppose that dramatic shifts will occur in this essential pattern in the near future. The experience of the past decade

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This chapter is drawn from the background paper prepared for this study by Walter S. Baer. We are indebted to him for his contribution.

Table 1
Conduct of Federal R&D
by Type of Performer and as Percent of Total
1967, 1971, 1976 (dollars in billions)

	1967	1971	1976
Federal Intramural	$3.4 (23%)	$4.2 (28%)	$5.6 (28%)
Industrial Firms	8.4 (58%)	7.7 (52%)	10.2 (51%)
Universities & Colleges	1.4 (10%)	1.7 (11%)	2.5 (12%)
FFRDCs Administered by Universities	.7 (5%)	.7 (5%)	1.1 (5%)
Other Nonprofit Institutions	.6 (4%)	.7 (5%)	.8 (4%)
TOTAL	$14.5	$15.0	$20.2

Source: National Patterns of R&D Resources, Funds and Manpower in the U.S., 1953-1976, Table B-1, pp. 20-21.

does not suggest any marked or fundamental changes in the roles of the respective R&D performing organizations. Yet there have been changes in the relationships between the universities and other R&D performers that merit close attention. Paradoxically, the universities have been both competing and cooperating with other research institutions in the past 10 years, and it is likely that this trend will continue.

The forces promoting competition are clear enough. Competition for research funds between universities and other research performers became more intense as federal R&D expenditures leveled off after their rapid growth in the 1950s and early 1960s. The slower growth in federal expenditures, combined with the impact of inflation on research budgets, has affected all researchers since the mid-1960s. Scientists and research administrators in government laboratories, industry, and nonprofit institutes have experienced many of the same problems as have those in universities: Research budgets are down; good researchers have been let go or turned away; plans to build new research facilities have been deferred or cancelled. Every sector of the research community, affected to some degree by the end of the Sputnik boom years, has had to adjust. Part of the adjustment process has been the search for new business and a more vigorous competition for increasingly scarce research funds.

The factors furthering closer cooperation spring from the same underlying forces: Since the academic demand for PhDs diminished in the late 1960s, universities have been urged to be more responsive to the direct manpower needs of industry and government. Furthermore, the call for "relevance" in university research has prompted closer associations with the government, industry, and nonprofit sectors in address-

ing problems perceived to be of national importance. Many voices within academe as well as industry have called for universities to redress their former neglect of industrial research problems.

Efforts by universities, especially engineering departments, to rebuild close ties with industry have been a striking feature observed in site visits for this study. Most institutions visited were busy with plans to seek out industrial support for research, arrange for closer contacts with industry spokesmen to find employment for graduate students, or simply to increase their communication with industry. The remark of one engineering department chairman is characteristic:

> Hell, in the 1960s money was pouring out of the federal government. Who cared about industry? We forgot about industry. We thought we didn't need them, but we were wrong. Now there is a much healthier view of how much we need industry, in all sorts of ways.

Any discussion of the changing university relationships with other research performers must begin with the observation that colleges and universities differ in their objectives and approaches. Some universities have large agricultural and engineering research programs that traditionally have been linked closely with government and industry. Dozens of universities have managed large programs of contract research for the Department of Defense (DOD) and other federal agencies, while others have consciously eschewed them. Some universities actively encourage faculty members to seek industrial consulting or engage in part-time entrepreneurship, while others frown on such activities. Because of the heterogeneity of American colleges and universities (one of the system's greatest strengths), any generalizations about academic research relationships must be made with caution; very likely they will contain exceptions. Other categories of research performers also vary in objectives and modes of operation. The industrial R&D sector, for example, includes firms tinkering with minor product improvements as well as institutions such as the Bell Laboratories that support more basic research than do most universities. Other sectors display a similarly wide range of attitudes and capabilities.

With the above caveat, then, this chapter addresses the universities' relationships with the following research performers:

- University contract research centers
- University-administered FFRDCs
- Project research institutes
- Government in-house laboratories
- Industrial firms

University Contract Research Centers: Moving Classified Research Off Campus

University-administered contract research centers, nearly all of which performed some classified research sponsored by federal defense agencies, became caught up in the wave of antimilitary protests during the late 1960s. Like other aspects of academic administration, university treatment of classified research was never particularly tidy or consistent. Such projects were often the direct outgrowth of a faculty member's consulting for DOD or serving on a defense agency panel.

Administering classified research in an academic environment raised not only problems of security in restricted access facilities but also questions of how such work would relate to traditional scholarship. A common solution was to establish a separate laboratory or center for classified contracts. Some centers were included as integral units of the university, such as the Instrumentation Laboratory at the Massachusetts Institute of Technology (MIT) and the Willow Run Laboratories at the University of Michigan; some were established as FFRDCs, such as the MIT Lincoln Laboratory and Johns Hopkins's Applied Physics Laboratory; and some were incorporated as separate institutions accepting both government and private research contracts, for example, the Stanford Research Institute and the Cornell Aeronautical Laboratory.

Two developments of the late 1960s promoted friction: Whatever their administrative arrangements with the sponsoring university, contract centers became one focus of student protests against the performance of classified research in an academic environment. Contract centers became targets of picketing, sit-ins, and increasingly more violent protests, including the bombing of the Army Mathematics Research Center at the University of Wisconsin in 1970. Moreover, passage of the Mansfield Amendment in 1969 implied that in the future academic contract research centers could do less basic research unrelated to defense missions. University and defense officials alike began to question the usefulness of close DOD/university ties and to reappraise relationships.

As a result, a number of universities decided to eliminate on-campus classified research, and in the process some cut loose from their contract research centers as well. Stanford University's severance of ties with the Stanford Research Institute (SRI) in 1970 was the largest and most publicized of these spinoffs. But there were others. A year earlier, the staff of the Stanford University Applied Electronics Laboratory transferred to SRI. In 1967 Columbia University converted its Electronics Research Laboratory to an independent, nonprofit institution renamed the Riverside Research Institute. The MIT Instrumentation Laboratory was separated from the university in 1973, renamed the Charles Stark Draper Laboratory, and reoriented from military guidance and control projects toward space, air transportation, and related

civilian research.[2] The University of Michigan converted its Willow Run Laboratories in 1972 to an independent, nonprofit institute emphasizing environmental research. Only a few contract research centers with annual expenditures of $1 million or more, such as the Denver Research Institute, still operate as integral parts of the sponsoring universities.

A particularly interesting case is that of the Cornell Aeronautical Laboratory (CAL), which was operated as a division of Cornell University although located 100 miles away near Buffalo. CAL was not classified as an FFRDC, since it accepted contracts from private as well as government sponsors, but much of its research was classified by the Department of Defense. In 1969, after students protested against classified work at CAL, the University tried to sell the Laboratory to a private firm. However, the state of New York, supported by many of the CAL employees, successfully sued to stop the sale. Blocked in its attempt to sell the Laboratory, Cornell University agreed to its conversion to a profit-seeking subsidiary, now renamed Calspan.

University divestiture has generally enabled contract research centers to broaden their R&D interests and to diversify their base of contract support. The effect on universities has been a more explicit arm's length and potentially competitive relationship between faculty and the centers.[3]

Separation was a natural consequence of a center's growth and maturity, as much as it was a result of the classified research controversy. Universities took on the responsibility for creating defense-oriented research capabilities at a time when they could offer the unique talents and resources to do so. By the late 1960s, more than 20 years after the end of World War II, many of these centers had become large, relatively stable institutions with interests quite different from those of their academic sponsors. The advantages to a university of receiving management and overhead fees from contract research, as well as providing research opportunities and specialized facilities for faculty members, were often outweighed by the disadvantages of managing an organization whose objectives were increasingly divergent from the institution's principal missions of teaching and basic research. From the contract research center's standpoint, university affiliation brought prestige and greater access to faculty members and graduate students, but it also carried with it the disadvantages of dealing with a university administration that often constrained the center's prospects for growth. Consequently, the separation of the contract center from the university has often proved to be in the best interests of both institutions.

University-Administered FFRDCs

The conflicts over classified research also turned against university-administered FFRDCs sponsored by the Department of Defense. As

Table 2
University-Affiliated FFRDCs
1966-1975

FEDERAL AGENCY SPONSOR/FFRDC	UNIVERSITY ADMINISTRATOR	CHANGE IN FFRDC STATUS, 1966-1975
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION (AEC)		
Ames Laboratory	Iowa State University	
Argonne National Laboratory	University of Chicago and Argonne Universities Assoc.	
Brookhaven National Laboratory	Associated Universities, Inc.	
Cambridge Electron Accelerator	Harvard University	Phased Out 1974
Fermi National Accelerator Laboratory	University Research Associates	Established 1968
Lawrence Berkeley Laboratory	University of California	
Lawrence Livermore Laboratory	University of California	
Los Alamos Scientific Laboratory	University of California	
Oak Ridge Associated Laboratory	Oak Ridge Associated Universities	
Princeton-Pennsylvania Accelerator	Princeton University and the University of Pennsylvania	Phased Out 1971
Plasma Physics Laboratory	Princeton University	
Stanford Linear Accelerator Center	Stanford University	
DEPARTMENT OF DEFENSE		
Applied Physics Laboratory	Johns Hopkins University	
Applied Physics Laboratory	University of Washington	Phased Out 1974
Applied Research Laboratory	Pennsylvania State University	
Army Mathematics Research Center	University of Wisconsin	Phased Out 1970
Center for Naval Analyses	University of Rochester	Became University Administered 1968
Center for Research in Social Systems	American University	Phased Out 1970
Human Resources Research Organization	George Washington University	Changed to Nonprofit Administered 1969
Hudson Laboratory	Columbia University	Phased Out 1969
Lincoln Laboratory	Massachusetts Institute of Technology	
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION		
Jet Propulsion Laboratory	California Institute of Technology	
Space Radiation Effects Laboratory	College of William and Mary	
NATIONAL SCIENCE FOUNDATION		
Cerro Tololo Inter-American Observatory	Association of Universities for Research in Astronomy, Inc.	
Kitt Peak National Observatory	Association of Universities for Research in Astronomy, Inc.	
National Astronomy and Ionospheric Center	Cornell University	Established 1970
National Center for Atmospheric Research	University Corporation for Atmospheric Research	
National Radio Astronomy Observatory	Associated Universities, Inc.	

FEDERAL AGENCY SPONSOR/FFRDC	UNIVERSITY ADMINISTRATOR	CHANGE IN FFRDC STATUS, 1966-1975
DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE		
Center for the Advanced Study of Education Administration	University of Oregon	Phased Out 1972
Center for Research and Development in Educational Differences	Harvard University	Phased Out 1967
Center for Research and Development in Higher Education	University of California	Phased Out 1972
Center for Research and Development for Learning and Reeducation	University of Wisconsin	Phased Out 1972
Center for the Study of the Evaluation of Instructional Programs	University of California	Phased Out 1972
Center for the Study of Social Organization of Schools and the Learning Process	Johns Hopkins University	Phased Out 1972
Coordination Center for the National Program in Early Childhood Education	University of Illinois	Phased Out 1970
Learning Research and Development Center	University of Pittsburgh	Phased Out 1972
Research and Development Center in Educational Stimulation	University of Georgia	Phased Out 1970
Research and Development Center in Teacher Education	University of Texas	Phased Out 1972
Stanford Center for Research and Development in Teaching	Stanford University	Phased Out 1972

shown in Table 2, five of the eight university-managed, defense-sponsored FFRDCs of 1966 had by 1975 been phased out or transferred to other sponsorship. Only the Applied Physics Laboratory operated by Johns Hopkins University, the Applied Research Laboratory managed by Pennsylvania State University, and MIT's Lincoln Laboratory remained university affiliated throughout this period.

For different reasons, the attempt by the Department of Health, Education, and Welfare (HEW) to establish university-administered FFRDCs for educational research proved unsuccessful. These centers were created toward the end of the R&D boom period by an agency that, unlike Defense and the Atomic Energy Commission (AEC), had little experience in contracting for mission-oriented research. Faced with growing stringency in research budgets, a change of administration, and congressional skepticism, HEW phased out its university-administered educational research FFRDCs or transferred them to other institutional managers in the early 1970s.

The university-affiliated FFRDCs supported by the National Aeronautics and Space Administration (NASA) and ERDA (the Energy Research and Development Administration, formerly the Atomic Energy Commission) have more stable histories. NASA's Jet Propulsion Laboratory and the ERDA multiprogram national laboratories have part-

ly diversified from space, atomic energy, and basic scientific research to applied work directed toward energy, the environment, and other national priorities. Five of the eight ERDA multiprogram FFRDCs—Argonne, Brookhaven, Lawrence Berkeley, Lawrence Livermore, and Los Alamos— are university administered, while two—Oak Ridge and Sandia—are managed by industrial firms, and one—Pacific Northwest—is operated by a nonprofit institution. With the formation of ERDA in 1975, these FFRDCs have been called on to broaden their efforts in support of energy development and demonstration programs. This will have the likely effect of moving the multiprogram national laboratories toward closer working relationships with industry, since industrial firms are intended to be the ultimate users of the energy technologies developed by ERDA. Whether strengthening such ties with industry will prove difficult for university-administered FFRDCs or require changes in their administrative structures remains to be seen.

The remaining university-administered FFRDCs supported by ERDA provide specialized research facilities for high energy physics, plasma physics, and other areas of nuclear science. However, the increasing costs of high energy accelerators resulted in the closing of some facilities (e.g., the Princeton-Penn Accelerator and the Cambridge Electron Accelerator) in order to free funds for the new Fermi National Accelerator Laboratory. The National Science Foundation also supports university-managed FFRDC facilities in astronomy and atmospheric science. One of these facilities, the National Astronomy and Ionospheric Center in Puerto Rico, was picked up from the Department of Defense in 1970 as a result of DOD's shifting some basic research support to civilian agencies after passage of the Mansfield Amendment.

The establishment of new national research centers seems possible in the future as more fields of science require large capital investments in research facilities with full-time staff to operate them. Frontier research in many fields may be conducted by user groups of scientists from different institutions sharing specialized facilities, as is done today in high energy physics, astronomy, and oceanography.[4] More biological and medical research will require special cell cultures or animals maintained in centralized laboratories. And social scientists see a parallel need to develop common data bases available to users from many institutions.[5] Although this trend toward sharing specialized research facilities already appears well established, available data are inadequate to document its full extent. In the future, some research centers now managed by a single university, and newly created national facilities for basic science, may be converted to the university-managed FFRDC category.

Project Research Institutes

Although the boundaries between university contract research centers and FFRDCs are ill defined, both differ from institutions incorporated

to perform research on specific grants and contracts. Such "project institutes" are, in the words of Harold Orlans, a close observer of R&D policy, "the most motley and volatile type of institute...[created] most frequently as ventures of faculty who, dissatisfied with the constraints on projects administered by their institutions, may be adventurous in their spare time while retaining the security of tenure."[6] A project institute may be little more than the extension of a professor's consulting practice, perhaps incorporated to obtain higher consulting rates than those paid by government agencies. The center may, however, develop a sizable staff and become a permanent entity. The Center for Policy Research, a project research institute in New York City, noted in its review of its first five years of operation:

> While the Center initially sought part-time senior staff [professors who combine their university affiliation with summer work of limited consulting at the Center], in recent years, full-time researchers have been added.[7]

From a professor's point of view, a project institute can bring added income, flexibility to do work that the university might not approve, and freedom from paying university overhead while still maintaining access to facilities such as the university's library and computers. From the government agency's standpoint, contracting with a project institute can mean faster research results at lower cost. Some professors reportedly have been encouraged to submit proposals through a project institute rather than through their university in order to meet an agency's time and budget constraints.

Such project institutes seem to be an inevitable part of a dynamic research system with multiple funding sources and performers. As research performers, they are the most responsive to new policy directions and changing research priorities of government agencies. Their potential for abuse—overcommitted faculty or unreimbursed use of university facilities—is apparent but seems largely controllable by sensible university regulations.

Project institutes headed by part-time faculty members appear to be proliferating rapidly. However, no reliable data are available on their numbers, funding levels, or importance as research performers. Although recent interviews with federal officials, faculty members, and university administrators indicate that project institutes have in the last decade become larger and more clearly distinguishable research performers, a more coherent description of their size, status, and role in the U.S. research system must await a more systematic survey.

Government In-House Laboratories

Universities now face greater competition for research funds than they did a decade ago. The competition is principally among the universities

themselves, though university administrators cite competitive pressures from nonprofit institutes and in-house government laboratories. Many believe that federal intramural research is taking an expanded *share of government R&D dollars. As* research budgets contract, the argument goes, federal agencies tend to favor their own in-house laboratories over universities and other R&D performers. Thus a 1975 Department of Defense study reported:

> We found that the in-house laboratory share of the DOD budget has increased by about 15 percent in the past six years. No compelling reason for increasing the laboratories' budget was found. To the contrary, there was some evidence of the laboratories being under strain to stay fully employed. Based on some Service studies and personal visits to most of the laboratories, it is believed that a modest reduction in the size of the in-house laboratories...could produce some savings and eliminate some excessive competition.[8]

Similarly, a 1975 ERDA report stated:

> There is the need, however, to address the beliefs, real or perceived, on the part of some members of industry and universities, that the [ERDA] laboratories do not make sufficient use of out-of-house research and development resources, are self-perpetuating, and, in fact, compete with them for limited federal research and development funds.[9]

The aggregate data reviewed in the previous chapter do not support this contention. Federal in-house laboratories have increased their share of federal R&D spending more than the university sector, but both have grown since 1966. In the distribution of federal spending for basic research, the university share has grown slightly faster than that of the intramural laboratories during the past decade. The largest relative gains for the federal intramural sector have come in the development category and at the expense of industrial firms.

However, the quality of federal in-house R&D is questioned more often than its quantity. As a recent National Academy of Sciences report (the Pound Report) noted with respect to the Department of Agriculture, few government agencies encourage peer review of their in-house research, which consequently may be below the standard of work performed at other institutions.[10] Maintaining high quality research is a perennial problem that receives more attention in times of financial stringency. Regular, high-level review of intramural agency R&D in relation to work in other institutions—perhaps by the recently created Office of Science and Technology Policy—seems advisable to encourage high quality research as well as to promote fair competition among research performers.

But it is in applied research that universities now face the most serious competition from other institutions. Most interdisciplinary and policy-oriented research falls into this category. Universities, with their

tradition of departmental autonomy and incentive systems for exclusive disciplines, have not moved easily into interdisciplinary research activities. Once they have, universities have found themselves in competition with a number of research institutions—private consulting firms, independent nonprofit organizations, and FFRDCs—that specialize in this kind of work.[11] Consequently, it is not surprising that academic institutions received only 50 percent of the applied research funds awarded by the National Science Foundation in 1975, compared with 86 percent of NSF grant moneys for basic research.[12] Given the large number and variety of institutions capable of conducting applied or policy-oriented research, it seems unlikely that universities will perform a significantly greater share of this work in the future.

University Relationships With Industry

The academic and industrial research communities have consistently held ambivalent attitudes toward each other. On the one hand, certain interactions were natural and desirable, e.g., university faculty consulting for industry, the hiring of university graduates by industry, firms sponsoring fellowships. Engineering faculty members have for many years received industrial support for research, worked in industrial laboratories during the summer, and sent graduate students to write dissertations in industry. Industrial firms have valued university contacts as windows to new developments as well as sources of expertise unavailable within the firm.[13] For many firms, a small investment in university research support or graduate student fellowships has been an effective means of extending their own research capabilities and obtaining early knowledge of new results.

On the other hand, academics and industrialists have traditionally been suspicious of each other's motives and modes of operation. The professor's condescending attitude toward the commercial exploitation of knowledge and the businessman's disdain for ivory tower research are familiar stereotypes.

Recommendations on how to improve university/industry relationships through joint research projects or other collaborative efforts abound. Yet the obstacles to closer collaboration are very real. Discussions of the issue consistently cite differences in research objectives and in the time frame for obtaining and reporting results, differences regarding publication and patent policies, and mutual misunderstandings exacerbated by a lack of communication.[14] The publication and patent problem is a particularly difficult issue. Professors want freedom to publish their research results, but a company sponsoring a joint research project wants to benefit from the information before its competitors can. Telling an industrial research manager that his firm cannot have proprietary rights to research it sponsors at a university is as dif-

ficult as telling the university professor that he can only publish his results anonymously. Neither approach is likely to generate much enthusiasm for joint research projects.

Since these barriers to university/industry cooperation are hardly new, it is instructive to begin with an analysis of how the coupling problems have worsened in recent years. Although hard evidence is lacking,[15] there are reasons to believe that the links between universities and industry weakened in the two decades following World War II and approached their nadir in the early 1970s. The principal factors behind the decline appear to have been:

> the separation of academic research from perceived industrial needs;
>
> the decreased interest among PhD and other graduates in industrial research; and
>
> the relative decline of basic research in industry.

Separation of Academic Research From Industrial Needs. The era of rapid growth of federal funds for academic research gave universities less incentive to maintain or strengthen their ties with industrial firms. Moreover, support from defense and space agencies drew university research, especially engineering, toward high technology and away from other industrial problems. Engineering faculty engaged in research on space vehicles or advanced radar systems found little in common with conventional industrial engineering. Defense and space research focused on *performance* improvements while other industrial R&D continued to emphasize *cost* improvements as well. There was no question that the former seemed the more interesting direction for university engineering faculty to pursue.

Some close working relationships developed between aerospace firms and university engineering departments in the 1950s and 1960s. Many new high technology firms were created as a result of academic research, and professors became their corporate directors or entrepreneurs. The high technology companies surrounding Harvard and MIT on Route 128 and the new electronics and instrument firms near Stanford became models for the rest of the nation. But because of the end of the Apollo program, the decline of defense support for university research, and the shift in national priorities, university engineering faculties often found themselves unfamiliar with the relevant industrial firms that had not ventured into high technology.

This situation was not prevalent in all engineering departments. Academic scientists researching certain topics—for example, exotic materials for space and defense applications—communicated with related manufacturing industries. But such efforts seemed more the exception than the rule during the 1950s and 1960s, especially at the most prestigious universities. Regional universities serving specialized clienteles

were more successful in maintaining their established industrial ties.

Decreased Student Interest in Industrial Research. The availability of federal funds for academic research and the general expansion of higher education in the 1950s and 1960s also drew students away from careers in industrial research. With the prospects of faculty appointments (often with promises of early tenure) in growing departments or at "centers of excellence," new PhDs naturally opted for academia over industry. And many professors were delighted to train their best students for careers in academic research. In an expanding era it was all too easy to believe that only the second-rate student or worse need be relegated to industry, government, or nonresearch teaching positions.

To the corporate research manager outside the aerospace and high technology industries, university training seemed less and less applicable to industrial needs. A 1973 American Chemical Society report stated that "there is no doubt that the structure of many graduate programs in chemistry has been oriented, unconsciously if not consciously, toward careers in academic research. Since at most a few hundred faculty and postdoctoral positions in chemistry became vacant each year, the bulk of the annual 2,000 or more chemistry doctors are being unrealistically trained."[16] "Too many [candidates for employment] are overspecialized in [their disciplinary] training and are not interested in broadening their horizons," wrote the vice president of R&D at Koppers Company.[17] "Send us well-trained graduates, free of antibusiness bias," said the general manager of research at Standard Oil (Indiana).[18] While industrial research managers undoubtedly have registered similar complaints in earlier years, concern over the imbalance between academic training and industrial research needs seems to have reached a peak in the late sixties and early seventies. Student protests against large corporations (among other institutions) at that time also contributed to the perceived weakening of university relationships with industry.

Declining Basic Research in Industry. A third factor contributing to weakened university/industry links was industry's diminishing role in basic research. As noted in Chapter II, industry's share of basic research spending declined steadily between 1955 and 1972, and the proportion of industry's own R&D funds spent on basic research dropped dramatically after 1966. Beyond these national statistics, discussions with individual corporate research managers confirm that industry's emphasis has shifted from basic to more applied research during the past decade. Inflation, an uncertain economy, and increased government regulation, among other factors, have led to corporate decisions to favor projects with short-term payoffs. In a widely quoted article entitled "The Breakdown of U.S. Innovation," *Business Week* reported: "...there is a growing sense that something has happened to American innovation...within a growing number of companies, such changes and pressures have led to a reappraisal of corporate goals and the emer-

gence of what one top research scientist dubs 'the MBA syndrome,' a super-cautious, no-risk management unwilling to gamble on anything short of a sure thing."[19]

Industry's shift away from basic research made working relationships with universities more difficult. The key to effective links between universities and industry is face-to-face, scientist-to-scientist contact. As Robert Sproull has observed from his career in both university and industrial research administration: "The most effective impedence transformer between industry and the university has been and is the able, articulate industrial scientist or engineer who visits a university to give a seminar and who talks informally with students in the lab."[20] Or as Jacob Goldman, chief scientist of Xerox Corporation, puts it: "Your admission ticket to the [basic research] club is to have something of your own to talk about."[21] As industry's commitment to basic research has declined, firms have generated fewer such admission tickets, and industrial scientists' links with their university counterparts have weakened.

International Comparisons

Despite these problems, the United States still appears to be superior in fostering relationships between universities and industrial firms, as perceived by other nations. The 1970 report of the United Kingdom Working Party on Universities and Industrial Research praises the "tradition of close collaboration between universities and industry" in the United States, citing federal research funding in universities and industry, university entrepreneurship (the Route 128 effect), and faculty consulting for industrial firms.[22] Comparative studies of the organization and financing of basic research in Europe and North America by the Organization for Economic Cooperation and Development (OECD) also points to this country's success in developing effective university/industry relationships.[23] The OECD review of the research systems in Germany, France, and the United Kingdom observes that "each [country] still looks with something approaching envy to the United States" in fostering strong industry/university links.[24]

Similarly, despite some concern on the part of university scientists, the site visits for this study found no evidence of any substantial "reverse brain drain" or migration of U.S. scientists and engineers to Europe. About a dozen instances were reported of faculty scientists leaving American universities for positions in European universities or research centers. There was no consistent pattern in these cases. Personal considerations often appeared to be a predominant factor, though inadequate research support was occasionally mentioned. Most postdoctoral fellows or assistant professors who spent time abroad returned to the United States, and many of them reported that conditions in

European laboratories had not been as favorable as they had initially hoped. European science has, however, made notable strides in some fields. More information and assessment of potential migration trends of American scientists to Europe lies beyond the scope of this study.

Prospects for Closer University/Industry Cooperation

University/industry relations were relatively weak in the early 1970s, but since then efforts have been made to improve them. Recent speeches and congressional testimony by both government officials and industry executives call for increased support for university research to provide the foundation for future technological innovation and economic growth. The theme is well expressed by the past president of the Industrial Research Institute: "...as a start, there must be strong support by government and industry for a major commitment to undirected basic research at the universities.... Only if we can be assured of a strong, viable university structure in its own right do we then have the basis for the integration of some added university efforts into broad national missions."[25]

For their part, universities also are seeking to rediscover their ties to industry. Research interest in solving the critical problems relating to the civilian economy is a factor, but other more practical matters are certainly involved: the availability of government funds for applied and problem-oriented research; greater university interest in industrial research support to supplement a static or declining federal share; changes in graduate student employment expectations; and a recognition that continuing education for industry may become a major source of university support in the 1980s and beyond.[26] Whatever the mix of motives, university faculty and administrators seem considerably more interested in strengthening their research ties to the private sector than they were five years ago. This appears especially true in the most prestigious universities, at which anti-industry protests and attitudes were strongest in the late 1960s.

Consulting and staff exchanges (an industrial scientist serving as a visiting professor or a faculty member spending a summer or sabbatical in industry) are the most direct ways of linking academic and industrial research. They are probably also the most effective means of transferring knowledge between the two sectors. Beyond these direct links, however, universities and industry have attempted other means to encourage closer collaboration as listed in Table 3 and described briefly below.[27] These means can be characterized as efforts to organize collaborative research projects and to improve the overall environment for knowledge transfer. In the past five years, NSF, the Small Business Administration, and the Department of Commerce have supported sev-

eral projects directed toward these ends. A brief discussion of these efforts follows.

Direct Corporate Funding of University Research. Although universities have always sought unrestricted research grants and endowment funds from industry, some have been wary of accepting corporate grants for specific projects or fields of research that might confer proprietary advantages to the donor. Others, however, seek industrial support more aggressively and are active in the technology transfer process. As one example, Harvard University and the Monsanto Company announced in February 1975 that Monsanto had agreed to provide up to $23 million for a 12-year program of biological and medical research at Harvard. "In return," according to a newspaper account, "Monsanto will have the opportunity to develop and distribute any medical materials growing out of the research."[28] In fact, the company is given exclusive licenses for a period of time to inventions made in connection with the Monsanto-supported research.

According to Harvard and Monsanto officials, Monsanto and the University have created a special advisory board of individuals not connected with either institution to review plans for publication, dissemination of information, and use of discoveries made under the program. In particular, the board has authority to require sublicensing of an invention if it believes such a step is necessary in the public interest. This arrangement nonetheless represents a substantial step away from some university policies that do not permit a firm to hold proprietary rights to inventions arising from university research it supports.

Table 3

Examples of University/Industry Collaboration

Mechanisms to Encourage Collaborative Research

- Direct corporate funding of university research projects
- Cooperative (cost-sharing) research programs
- University/industry research consortia
- Joint industry/university laboratories

Mechanisms to Encourage Knowledge Transfer

- Consulting
- Technology licensing and technological brokers
- Extension services
- Industrial associates programs
- Industrial parks
- Innovation centers
- Small business institutes

Bilateral arrangements between a university and an industrial firm generally result in person-to-person interactions that favor technology transfer. The firm presumably supports the research in expectation of a net economic return. In the past, such industrial support has typically been on a project-by-project and year-by-year basis.[29] In hard times these projects are often the first to be cut off. In contrast, the Harvard-Monsanto arrangement represents a long-term, high-level commitment by the Company to support basic science in return for closer links to university research and some proprietary advantages.

Cooperative Research Programs. In some cases individual firms may be willing to pay for part of the cost of a university research project. If the project offers prospects of educational or social benefits (such as creating jobs), the remaining costs may be paid for by a government agency, a private foundation, or the university itself. Federal support for such cooperative research can also be justified in cases of market failure where individual firms cannot recoup the benefits from R&D and consequently conduct little research. These arguments were used in the early 1960s to support cooperative research between universities and textile firms under the short-lived Civilian Industrial Technology Program in the Department of Commerce. At present the National Science Foundation through its RANN program sponsors cooperative research programs at Carnegie-Mellon University, North Carolina State University, and MIT. (Another program operated by the MITRE Corporation under the RANN cooperative research program is actually a form of technology brokerage. See page 72.)

The Processing Research Institute (PRI) at Carnegie-Mellon University was funded by NSF in 1971 to develop a Master of Engineering program oriented toward the processing industries. Cooperative research projects supported by individual firms form an integral part of the PRI program. In the three and a half years between January 1972 and June 1975, 26 firms and industrial associations paid approximately $800,000 to support 34 separate research projects.[30] PRI provided another $500,000 in matching funds from its NSF grant. The sponsors of research projects at PRI were large industrial corporations heavily involved in R&D, including Dupont, Exxon, Xerox, Westinghouse, Alcoa, and Ford. Few companies with annual sales below $100 million have participated.

The PRI program uses cooperative research projects to involve graduate students in problem-oriented research directly relevant to industrial needs. The program is not aimed at improving productivity in participating firms, nor is it addressed to any specific market failures. It is by no means clear, for example, that the federal contributions to PRI research projects do not simply substitute for the funds the companies would have spent on research anyway, albeit in their own laboratories and not at Carnegie-Mellon. Nevertheless, the PRI program represents

a direct effort to use federal funds as a catalyst to reorient university engineering studies toward industrial interests.

Similarly, the RANN-funded Polymer Processing Program at MIT seems directed toward large firms in the plastics industry with substantial R&D capabilities. Although one of the principal goals of the program is "to recommend alterations in public policy which would result in increased R&D investments and efforts by small firms,"[31] the five initial industrial participants are large corporations with annual sales ranging from $40 million to over $10 billion. According to a preliminary evaluation, "a great deal of informal interaction exists between the program staff and industrial members...and a high degree of satisfaction with the program is indicated by member firms."[32]

In contrast, the RANN-sponsored cooperative research program at North Carolina State University is directed toward the U.S. furniture industry, which is highly fragmented and conducts little R&D. Six furniture manufacturing firms participate in research projects with the University. As might be expected, establishing effective links has been more difficult in this case because of the companies' limited R&D capability. The preliminary evaluation reports that the Furniture R&D Applications Institute "is not meeting the cost-sharing goal" and that "the depressed economy has had substantial negative impacts on the development of the program. Industrial members hesitate to implement innovative processes and change furniture design when their revenues are uncertain and decreasing."[33] Moreover, the evaluation notes that while "the Institute's establishment was announced in the trade publications, and presentations have been made to the National Association of Furniture Manufacturers...and the Forest Products Research Society,...no results have been observed from these efforts."[34]

While it is still too early to judge the final results of NSF's efforts to stimulate cooperative research, these three contrasting examples support the view that universities can more easily create research partnerships with large, technically sophisticated companies than with small firms.

University/Industry Research Consortia. Another emerging approach to strengthening university/industry ties is the creation of research consortia with well-defined applied research objectives. The Department of Defense successfully adopted this approach for developing certain kinds of military technology, such as coatings for refractory metals in supersonic aircraft.[35] A group of experts in the field defines the key research needs, solicits proposals from both university and industry groups, selects the best proposals for funding, and coordinates the reporting and publication of results. Informal meetings of members to discuss their ongoing work have been instrumental in the success of research consortia.

An example of such a consortium in a nonmilitary field is that organ-

ized by Clemson University to conduct research on fabric flammability with support from the Experimental Technology Incentives Program (ETIP) of the Department of Commerce. ETIP viewed the consortium as a vehicle to speed the commercialization process from laboratory research to demonstration to subsequent diffusion. The consortium includes three universities, a nonprofit laboratory, a government laboratory, and four private firms.[36] Although in operation for only two years, the consortium seems successful in linking university research to industrial needs and in stimulating additional industry R&D.

In general, research consortia made up of universities and industry appear most productive when they are directed toward the achievement of a specific goal. A federal agency or other sponsor is usually necessary to provide the rationale and the financial support. If the consortium is willing to set research priorities, bring the participants together to discuss and critique each other's work, and otherwise act as a strong research coordinator, it can serve to build effective ties between universities and industrial firms. ERDA has indicated interest in establishing university/industry consortia for research on energy problems.

Some states are also active in creating consortia of state and local government agencies, universities, and industrial firms to conduct research on issues of state concern. Michigan, for example, established in 1975 the Michigan Energy and Resource Research Association (MERRA), whose members include state government agencies, large industrial firms such as Dow Chemical and Detroit Edison, and major universities, including Michigan State University, Michigan Technological University, the University of Michigan, and Wayne State University. MERRA's stated purposes are to aid the creation of research consortia among its members, identify research projects and likely funding sources, and help obtain support for these projects.[37] MERRA has endorsed such projects as the study of *in situ* oil shale reporting, involving Dow Chemical and several Michigan universities, and the conversion of municipal waste to methane, involving a private engineering firm and researchers at Michigan State University and the University of Michigan. MERRA also has been actively seeking to have the new ERDA-sponsored Solar Energy Research Institute located in Michigan. Several other states reportedly are considering emulating the MERRA model to enhance their competitive positions for energy R&D funds.

A different model is the Gulf Universities Research Consortium (GURC) that brings together research groups from several universities to conduct environmental research sponsored by government and industry. The consortium is controlled by the universities, with industrial firms, nonprofit research institutions, and government agencies involved as research associates or affiliates. Although consortia of this type may be useful in promoting cooperation among universities and in

obtaining research contracts, they seem less likely to build strong working relationships between universities and private-sector firms.

A Joint Industry/University Laboratory. Part-time use of specialized research equipment in universities by industry personnel, or vice versa, is not uncommon and may become more prevalent. University-managed contract research centers that engage in some research for industry are also widespread. Much more unusual, however, is the actual merger of university and industry laboratories into a single entity under joint control. One such example is the Fluid Dynamics and Energetics Laboratory of New York University (formerly the Aerospace Laboratory), which in 1973 was combined with the General Applied Science Laboratories (GASL), a for-profit company.

In 1973, New York University sold its University Heights campus and transferred most of the technical equipment, along with the faculty of the School of Engineering and Science, to the Polytechnic Institute of New York. But because the Institute already had sufficient facilities, the equipment and staff of the NYU Fluid Dynamics and Energetics Laboratory were merged with those of GASL. Although the physical facilities of the two laboratories have been combined, the professional staffs remain organizationally separate, and NYU and GASL use separate accounting systems for their operations. Complex legal and administrative issues remain, such as the disposition of government-furnished equipment and the cost apportionment of common services, but in principle these problems appear to be workable. A recent management study suggests that this arrangement can serve as a model for industry/university collaboration.[38] However, the NYU-GASL merger seems a forced marriage that, because of the basic differences between universities and for-profit organizations, is not likely to be replicated easily.

Encouraging University/Industry Knowledge Transfer

In addition to collaborative research, various approaches have been attempted to speed the transfer of knowledge from university research to industrial application. Government has provided the impetus for a number of such efforts in the past five years. The arrangements described below are by no means exhaustive, a more complete list is contained in the 1970 United Kingdom report of the Working Party on Universities and Industrial Research.[39]

Consulting. A traditional and effective means of knowledge transfer comes from consulting done by faculty for industry. Through consulting, university professors better understand industrial research needs and appreciate the problems of commercialization. However, few data exist in this area. A 1966 survey of University of California faculty members found that about 30 percent had done some consulting during

that year, especially those in the fields of medicine, engineering, and social science.[40] A 1969 survey of about 2,500 business school faculty showed that 40 percent served as paid consultants to private firms. Of the responding faculty members in private universities, over half were consultants, compared with about one third in public universities. Moreover, the percentage of business school faculty employed as consultants to national corporations increased according to the prestige of the university, while no such variation was found for local consulting.[41] Finally, an American Council on Education survey during the 1972-73 academic year found that 48 percent of responding faculty members reported some paid outside consulting during the previous year.[42]

These data are too meager to suggest any trends in academic consulting for industry. Frequent reports are heard about specific companies that have either abandoned or cut back on university consulting because of financial difficulties; on the other hand, some firms have begun using university consultants on a more systematic basis. Several corporations heavily involved in R&D, for example, have recently established technical advisory boards that include academic consultants to review their overall R&D strategies and programs.[43] No clear pattern of trends in consulting emerged from the site visits conducted for this study, except that faculty scientists, and particularly engineering faculty members, have shown a great interest in enhancing ties of all sorts with industry. To the extent that many faculty perceive consulting relationships as leading to further ties of potential mutual benefit, it seems probable that the time and effort devoted by faculty members to seeking out and engaging in consulting activities have increased substantially in the past few years and will continue to increase. Better data on faculty consulting to industry (perhaps as one of the NSF science indicators) would be helpful in observing trends in university/industry interactions.

Technology Licensing and Technological Brokers. A technological broker linking those universities with particular research capabilities to industrial firms with corresponding research needs is an appealing concept. Several types of brokers now exist: (1) university research foundations that license patents derived from university research;[44] (2) Research Corporation, Battelle Development Corporation, and other research corporations that license or otherwise commercially exploit inventions; and (3) private consulting firms, such as Dr. Dvorkovitz & Associates, which specialize in technology brokerage between universities and industrial firms. Since 1973, Dr. Dvorkovitz & Associates has sponsored an annual University/Industry Forum at which universities can display their technologies for license. According to the firm, the February 1976 meeting, called the "First World Fair for Technology Exchange," drew more than 2,000 attendees. Although data on the extent of university technology licensing are unavailable, both universities and commercial firms seem to be showing increased interest.[45]

Federal agencies have in the past supported dissemination centers or clearinghouses at universities to speed the flow of research results to potential industry users, but their effectiveness as agents of technology transfer remains in doubt.[46] More recently, NSF has funded a direct brokerage experiment as part of its cooperative research program. The New England Energy Development System (NEEDS) center, developed by the MITRE Corporation, is intended "to facilitate the flow of technology between the New England electric utilities and those universities/nonprofit research groups capable of performing research needed by the utilities."[47] The NEEDS center tries to match research performers and utilities on individual projects, publishes summaries of research results on specific topics, and conducts seminars for industry, government, and university participants. However, it is not clear what additional function a government-supported center serves for electric utilities that not only have their own industry supported R&D programs through the Electric Power Research Institute, but also have some established links with universities and other research performers. Without an identified market failure, a government-subsidized technology broker may simply serve as a substitute for other linking mechanisms provided by the private sector and the universities themselves.

Extension Services. The USDA Agricultural Extension Service, which along with the Agricultural Experiment Stations is closely tied to land-grant universities, is repeatedly cited as a model for knowledge transfer in other fields. A 1963 report by Arthur D. Little, Inc., for example, recommended an extension service for the construction industry modeled after the agriculture experience.[48] Some of the ideas contained in the A.D. Little report were subsequently embodied in the Department of Commerce's Civilian Industrial Technology program, but this part of the CIT program was never approved by Congress. Other proposals in the past 10 years have called for extension services to aid local governments, vocational rehabilitation programs, marine activities, pollution control, and energy conservation.

In June 1976, Texas A&M University organized the Energy Advisory Service for Texas (EAST). As an extension service, its purpose is to provide "direct contact of energy technology specialists with energy-user groups. The specialists [will] work with manufacturers, builders, operators of buildings, and the general public to perform energy audits and to analyze the potential payoff of energy conservation strategies."[49] EAST receives support from the University's state funds, the Texas Governor's Energy Advisory Council, Public Technology Incorporated (a nonprofit organization financed largely by NSF to stimulate technology transfer for local public services), and ERDA. Independently, ERDA is now considering establishing energy conservation extension services throughout the United States.

Proponents of new extension services emphasize the value of decentralized operations, grassroots knowledge, and adaptation to local problems and needs. These characteristics of the Agricultural Extension Service are well linked to the decentralized and locally varying farming operations throughout the nation. In general, extension services seem most appropriate for fragmented markets where the cost of obtaining information about new developments is high. Energy conservation for residential and commercial buildings may be one such example. Extension services are expensive to operate, however, especially if they must be created anew for each application. Building on an existing agricultural extension service, as Texas A&M has done for energy conservation, seems a more sensible approach.

University Industrial Associates. A few universities successfully run Industrial Associates programs, in which member companies each contribute an annual fee—usually $15,000 to $25,000. The funds are used for general university purposes rather than specific research projects. In return, Industrial Associate members receive publications, attend special conferences and seminars, visit campuses, and meet individual faculty members. Industrial Associate members do not expect to receive proprietary information from their campus contacts, but they can use their favored status to exchange research results in fields they are actively pursuing and to receive intensive briefings in unfamiliar areas by a competent authority. Consulting by a faculty member often grows out of an Industrial Associate contact, but that is an entirely separate arrangement.

Only a few of the nation's most prestigious academic institutions, such as MIT, Stanford, and the California Institute of Technology, have successfully run Industrial Associate programs. Several other universities that have attempted to institute them have failed to achieve the critical mass of corporate members needed to defray the costs of running the program.

Industrial Parks. Creating an industrial park near campus has been contemplated by many universities as a way of strengthening interactions with industry. Such a project is also financially attractive to universities with nearby available land. The most successful example is the Stanford Industrial Park, which has succeeded in attracting a large number of research-intensive companies and their spinoffs to locations near the Stanford campus. The increased opportunity for faculty consulting and entrepreneurship, industrial staff enrollment in university courses, and the use of industrial scientists as university lecturers stimulate technology transfer.

Other universities have emulated the Stanford project with varying degrees of success. The Research Triangle Park, developed with strong backing from the state of North Carolina, is associated with the University of North Carolina at Chapel Hill, North Carolina State University

at Raleigh, and Duke University at Durham. The largest research-intensive company to locate in the Park is Burroughs-Wellcome, a major pharmaceutical company closely connected with the biochemistry research activities at the University of North Carolina. To augment the industrial Park, the three universities joined to establish the Research Triangle Institute (RTI) as an independent, nonprofit research organization. The Institute's board of governors includes state government officials, representatives from corporations located in the Research Triangle Park, as well as university officials. Many university faculty work on industry-sponsored research as consultants or part-time members at the Institute. The Institute has some research capabilities that the universities lack, and joint efforts between the Institute and university researchers to secure federal research funds are fairly common. The Institute also contributes a small annual payment to the universities for research support. The relationship between the Institute and the member universities generally has been good, although there are signs of increased competition within some departments as faculty scientists have moved into applied areas in an effort to maintain their levels of research support.

A university decision to pursue an industrial park development certainly will be based on criteria other than the fostering of university/industry research relationships. It will demand very strong political and financial commitments by the university and the local government. And it seems clear that only a limited number of universities can successfully follow the Stanford and RTI examples.

Innovation Centers. Another group of National Science Foundation experiments intended to foster productivity in U.S. industry are the three "innovation centers" supported at the University of Oregon, MIT, and Carnegie-Mellon University. The innovation centers provide college-credit courses intended to teach the skills necessary to move a new product from the laboratory to the marketplace. The centers also provide support for individual inventors. If successful, the innovation centers should strengthen the links between universities and the industrial firms that will manufacture and market the new products.

In June 1973, NSF awarded grants totaling $3 million to the three innovation centers for efforts over a period of five years. It is too early to assess their results in terms of encouraging stronger university/industry ties, but they have generated considerable enthusiasm on the part of students, faculty members, and industry executives. As one example, five students at the MIT Innovation Center developed new electronic games in response to the interest displayed in marketing them by a small local company. A marketing contract with the company was signed in April 1975. According to the Center's director, "By the middle of July orders for 400,000 units had been obtained from major retailers around the country. Since production began on November 28, 1975, the

contractor has hired 70 new employees and created a pool of 100 additional people upon which to draw as production expands."[50] Overall, the NSF program director estimates that "during the first two years, the Centers contributed to the creation of 240 new jobs and $3.4 million in sales."[51]

University Business Development Centers. At least six federal agencies, including HEW, the Small Business Administration, NSF, the Economic Development Administration, the Office of Minority Business Enterprises, and the National Bureau of Standards, support programs at colleges and universities to assist small businesses. Generally, they offer management consulting and training in such fields as accounting, economics, contracting, and business law. The Small Business Administration has recently announced the formation of University Business Development Centers (UBDCs) that would coordinate these several agency efforts.

Most universities and colleges that participate in UBDC programs are urban, community-oriented institutions with little ongoing research. Consequently, while these small-business programs may stimulate technology transfer indirectly (by helping establish new firms that may then acquire technology from universities), their direct effect on university research links with industry appears to be minimal.

Conclusions

This chapter has sought to identify various important changes in the relationships between universities and other R&D performers. While the changes do not amount to a major alteration in the U.S. research system, which remains a mix of diverse institutions, each performing fairly distinct tasks, there have been some noteworthy developments affecting the universities. The changes have tended to move the universities into a position of both greater cooperation and more intense competition with other research performers.

The nation's growing concern for civilian problems and economic competitiveness has focused attention on university research links with industrial firms. The universities themselves have been anxious to restore close traditional ties with industry. Both the industrial and the academic sectors have shown a strong desire to rectify their neglect of each other in the recent past and to establish better relationships. In attempting to strengthen these links, however, they have encountered difficulties. Universities and industrial firms have often discovered that they have different objectives, different incentive systems, and different approaches to research that have not been easy to bridge, despite good intentions on each side.[52]

The problems involved in greater industry/university cooperation will be substantial, and rapid movement toward greater cooperation

should not be anticipated based on recent experience. Yet the beginnings of a closer relationship are discernible. Much can be done to dispel the myths that have made university/industry relationships more difficult than they need be. As attitudes and expectations change among university faculty, students, industrial scientists, and research administrators, a more favorable climate will emerge for cooperative ventures and closer communication. Though it seems unlikely that industry will retake the position it held before 1955 as a supporter of academic research, industry research support continues to be very important in many specific cases.[53]

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1. Albert H. Teich, W. Henry Lambright, and Paul J. Flynn, *Basic Research and Federal Laboratories: Problems of Institutional Choice, A Report to the Office of Planning and Policy Analysis* (Washington, D.C.: Office of Planning and Resources Management, National Science Foundation, December 15, 1975), pp. vi-vii.

2. In the spirit of the nation's Bicentennial celebration three years hence, the Charles Stark Draper Laboratory issued its own Declaration of July 1, 1973: "When in the Course of Human Events it becomes necessary for two Institutions to revise the Bonds which have connected them,...it is entirely fitting that this Separation take place and it is likewise fitting for us to solemnly Publish and Declare that the Charles Stark Draper Laboratory is, and of Right ought to be, a free and independent institution, with full Power to contract Alliances, establish Commerce and do all other Acts and Things which Independent Laboratories may of right do...."

3. Harold Orlans, ed., *The Nonprofit Research Institute: Its Origin, Operation, Problems and Prospects* (New York: McGraw-Hill, 1972), pp. 126-132.

4. Albert Crewe and Frank Press, among others, have proposed that the federal government give greater emphasis to the support of national research facilities. See Albert V. Crewe, "Science on a Regional Scale," in *Science and the University*, Boyd R. Kennan, ed. (New York: Columbia University Press, 1966); and Frank Press, "New Arrangements for Science in the Universities," *Science*, July 18, 1975, p. 177.

5. A recent review committee of the National Academy of Sciences has called attention to the need for large-scale data bases in the social sciences. See *Social and Behavioral Science Programs in the National Science Foundation*, final report of the Committee on the Social Sciences in NSF (Washington, D.C.: National Academy of Sciences, 1976).

6. Harold Orlans, op. cit., pp. 42-43.

7. Nancy Castleman and Pamela Coty, *Center for Policy Research: The First Five Years, 1968-73* (New York: Center for Policy Research), p. 6.

8. J.L. Allen, et al., *The DOD Laboratory Utilization Study* (Washington, D.C.: U.S. Department of Defense, April 1975), pp. xiii-xiv.

9. *Report of the Field and Laboratory Utilization Study Group* (Washington, D.C.: U.S. Energy Research and Development Administration, December 1975), p. 32.

10. *Report of the Committee Advisory to the U.S. Department of Agriculture* (Washington, D.C.: National Academy of Sciences, 1973). Similar criticism is contained in Andre Mayer and Jean Mayer, "Agriculture, The Island Empire," *Daedalus*, Summer 1974, pp. 83-96.

11. For a comparative discussion of interdisciplinary research in universities, independent research centers, and government, see Jack M. Nilles, "Interdisciplinary Policy Research and the Universities"; W.S. Baer, "Interdisciplinary Policy Research in Independent Research Centers"; and P. Polishuk, "Problems in Interdisciplinary Policy Research and Management in Government," *IEEE Transactions on Engineering Management*, May 1976, pp. 74-84, 92-100.

12. *Federal Funds for Research, Development and Other Scientific Activities*, Vol. XXIII, Detailed Statistical Tables (Washington, D.C.: National Science Foundation, 1974), p. 47, 67.

13. Or in the words of one industrial research manager, the director of the Rockwell International Science Center: "There are a lot of advantages...to working with universities.... One is the outstanding creative talents. That does not mean we do not have them in industry; it just means our people get numb sooner." In T.L. Loucks, "Univer-

sity-Industry Joint Projects: An Industrial View," *Journal of the Society of Research Administrators*, Spring 1974, p. 35.

14. See, for example: United Kingdom Working Party on Universities and Industrial Research, *Industry, Science, and Universities* (London: Confederation of British Industry, 1970), pp. 56-57, 88-89; and Joseph F. Libsh, "The Role of the Small, High Technology University," *Research Management*, May 1976, pp. 28-31. Most of the published literature on this topic consists of personal statements and calls for "better communications" between the two sectors; a thoughtful and perceptive exception is Rustum Roy, "University-Industry Interaction Patterns," *Science*, December 1, 1972, pp. 955-960. Additional efforts to develop an analytic framework for and quantitative data about U.S. university/industry interactions would seem highly useful.

15. Attempts to chart university/industry relationships by observing the number of ideas or events in the university sector that have led to industrial innovation seem of little help. The relative importance of the university-initiated ideas depends principally on the time frame used in the analysis as a comparison of the Hindsight and Traces studies indicates. The longer the time horizon, the more likely the innovation will have some university roots.

16. *Chemistry in the Economy* (Washington, D.C.: American Chemical Society, 1973), p. 445.

17. W.N. Maclay, "Science-Engineering Education for Industrial Research," *Research Management*, September 1974, p. 34.

18. P.C. White and C.C. Wallin, "What Industry Needs From Academia," *Research Management*, September 1974, p. 30.

19. *Business Week*, February 16, 1976, pp. 56-58.

20. R.L. Sproull, "The Industrial-Academic Interface: From the Academic Viewpoint," *Research Management*, May 1969, pp. 219-226.

21. J.E. Goldman, "The Need for Basic Research in Industry," *Physics Today*, December 1975, pp. 23-25.

22. United Kingdom Working Party on Universities and Industrial Research, *Industry, Science, and the Universities* (London: Confederation of British Industry, 1970), p. 108.

23. *The Research System* (Paris: Organization for Economic Cooperation and Development, Vol. 1: France, Germany, United Kingdom, 1972; Vol. 2: Belgium, Netherlands, Norway, Sweden, Switzerland, 1973; Vol. 3: Canada, United States, General Conclusions, 1974).

24. Ibid., Vol. 1, p. 249.

25. Herbert I. Fusfeld, "Industry/University R&D: New Approaches to Support and Working Relationships," *Research Management*, May 1976, p. 24.

26. R.A. Swalin, "Improving Interaction Between the University and the Technical Community," *Research Management*, May 1976, pp. 25-27.

27. Roy discusses several of these institutional mechanisms in more detail. See Rustum Roy, "University-Industry Interaction Patterns," *Science*, December 1, 1972, pp. 955-960.

28. "Monsanto, Harvard Join in Project," *St. Louis Post-Dispatch*, February 6, 1975, p. 18.

29. For example, note the approach described by Alcoa's vice president for science and technology: "The device used...is to tell a young industry researcher to visit the university which is doing the best work in his field, then provide him with a check, in Alcoa's case for $5,000, which the young industry representative can leave with the professor to help support a graduate student or to provide general support for the work, but to leave it only if he thinks the work being done is good and useful. Since most professors hope the industry representative will visit again next year with similar results, there is a real incentive to communicate and to establish a lasting relationship." In Eric A. Walker and Robert G. Hampel, "Improving Industrial R&D: University Relations," *Research Management*, September 1974, pp. 23-28.

30. *Fourth Annual Progress Report* (Pittsburgh: Processing Research Institute, Carnegie-Mellon University, June 1975).

31. Marcia L. Grad and Joseph Halpern, "Evaluation Status and Planning, Cooperative Research and Development Experiment," Report R 75-07, October 1975, p. 23. Prepared by the Denver Research Institute for the Experimental R&D Incentives Program of the National Science Foundation.

32. Ibid., p. 26.

33. Ibid., p. 20.

34. Ibid., p. 18.
35. Rustum Roy, op. cit.
36. Richard A. Rettig, "The Use of Consortia for the Management of Research and Development: Some Initial Observations on the Clemson University ETIP Project" (Paper presented at the Clemson University Special Symposium on Flammability and Flame Retardation of Polyester/Cotton Blend Fabrics, Clemson, South Carolina, September 15-17, 1976).
37. *Merra '75 Annual Report* (Detroit: Michigan Energy and Resource Research Association, 1976).
38. John R. Ragazzini, "Management Study of a Merged Large-Scale Fluid Dynamics (and Energetics) Laboratory—A Joint University-Industry Venture" (New York: New York University, July 1976).
39. United Kingdom Working Party, op. cit., p. 112.
40. Dallas K. Perry, "Sample Survey of Faculty Supplementary Employment and Income During 1965: University of California and California State Colleges, Final Report," TM-L-2789 (Los Angeles: System Development Corporation, December 30, 1965).
41. Carlos E. Kruytbosch and David D. Palmer, "Academic Role Performance and Organizational Environment" (Mimeographed, 1976). University prestige determined by "peer-based prestige ratings of institutions," according to the authors.
42. Alan E. Bayer, "Teaching Faculty in Academe: 1972-73," *ACE Research Reports*, Vol. 8, No. 2 (Washington, D.C.: American Council on Education, August 1973).
43. Frank R. Bacon, Jr., and Thomas W. Butler, Jr., "The Technical Board," attachment to "Identifying Needs and Resources for Knowledge of Science" (Paper delivered by Thomas W. Butler, Jr., at the annual meeting of the American Association for the Advancement of Science, February 1976).
44. Raymond D. Daniels, Ralph C. Martin, Lawrence Eisenberg, Jay M. Lewallen, and Ronald A. Wright, "University-Connected Research Foundations, An Introduction," *SRA Journal*, Spring 1975, pp. 16-25.
45. Rebecca L. Rawls, "University Technology Licensing Set to Rise," *Chemical and Engineering News*, *August 24, 1975, pp. 11-12.*
46. Samuel I. Doctors, *The Role of Federal Agencies in Technology Transfer* (Cambridge, Mass.: MIT Press, 1969), pp. 92-127.
47. Marcia L. Grad and Joseph Halpern, op. cit., p. 29.
48. Dorothy Nelkin, *The Politics of Housing Innovation* (Ithaca, N.Y.: Cornell University Press, 1971), pp. 25-26.
49. Stephen Ritter, "The Energy Advisory Service for Texas" (Paper presented at the 1976 Summer Workshop on Energy Extension Services, Berkeley, California, July 1976, Mimeographed).
50. Y.T. Li, "Development of Future Innovators and Entrepreneurs" (Paper delivered at the annual meeting of the American Association for the Advancement of Science, February 1976).
51. Robert M. Colton and Gerald G. Udell, "The National Science Foundation Innovation Centers: An Experiment in Training Potential Entrepreneurs and Innovators," *Journal of Small Business Management*, April 1976, pp. 11-20.
52. As one reviewer comments: "If the idea of collaboration between university and industry is buried underneath sufficient platitudes, it will die of suffocation." In D.C. Freshwater, "Industry, Science and Universities," *Chemistry and Industry*, March 20, 1971, pp. 320-321.
53. P.H. Abelson, "Additional Sources of Financial and Political Support for Science," *Science*, April 20, 1973.

IV

Current Developments in Academic Science and Engineering

Because of great diversity among fields of science and engineering, few broad generalizations about the research effort are possible. External circumstances of funding, graduate enrollments, and social priorities affect different fields in varying ways. Detailed analyses of each field are necessary. The overall impression is one of continued research vitality, although this is more characteristic of the first-rank research departments. Less highly ranked departments have generally experienced serious difficulties in the austere funding environment of recent years. A serious issue is whether the quality of the leading science departments will also erode in the future.

Chapter IV

Current Developments in Academic Science and Engineering

The scientific effort in universities is characterized by enormous variety within and among scientific fields, by sharp contrasts in the quality of departments, and by the striking differences in the types of research undertaken as well as the scale of research efforts. This significant heterogeneity reflects both the diversity of academic research institutions and the scientific developments within each field. The broad environment for university research and developments in science, however, do not provide the total picture. It is important also to probe more deeply into the specific fields of science and understand the particular circumstances affecting each.

This chapter reviews the salient developments in five major fields of science and engineering, the distinctive factors affecting each field, and other detailed considerations that might otherwise be overlooked in a discussion of more general trends. We cannot in this report exhaustively treat the substantive developments within each field, but we can suggest the major factors that bear on the vitality of a particular field. Our site visits as well as the disciplinary reviews by authorities from each field form the major basis for the discussion.

There are great differences among scientific fields: Each has peculiar problems, as do the subfields within a larger field; generalizations are therefore difficult. For instance, the decline in graduate enrollments that struck physics and mathematics has not affected the life sciences, where enrollments have continued to show overall increases. Physics started from a larger base; it was the first field to be well instrumented and amply funded for research. But it is now the field that recently has experienced the sharpest declines in funding. Mathematics has a number of distinctive problems: The pure mathematics areas have become

highly dependent on a single government agency for support. Swelling undergraduate enrollments in mathematics courses create special instructional needs that in turn affect research efforts and graduate programs in many departments.

The impact of the medical schools has special bearing and relevance for the life sciences. Engineering, with its dependence on special kinds of facilities, has different instrumentation needs from other disciplines. The facilities required for engineering research are considerably more elaborate than the "middle-range" facilities of much research in physics, chemistry, and the life sciences.

The list of the distinctive problems faced by each discipline is a long one, and special nuances affect each field. Any broad analysis of the state of academic science should carry the caveat "in the field of_____" attached to nearly every statement; where the context does not make this point clear, we have tried to specify the qualifications that must be noted. Nonetheless, it is still striking how many problems and tendencies seen in our visits are common to many disciplines and institutions.

We begin with several general observations: First, the substantive vitality and excitement of most scientific fields continue to be strong; second, tendencies toward stratification (or restratification) among departments are increasingly evident; third, rapid changes have taken place, creating uncertainties for the future. Finally, while it is difficult to document, the generally more austere funding environment has appeared to contribute to a somewhat more cautious atmosphere in science research. Some scientists appear less willing to take risks.

Achievements of great consequence in American science are evident in many fields, but a recitation of recent significant events will not be made here. The noteworthy point is the strength and vigor of the overall scientific effort and its continued high quality and promise. Yet, as mentioned earlier, there are now signs that the American share of total world publications in some fields has slipped slightly relative to the achievements of other nations' scientists.[1] Thus, this generally bright picture has another side to it: the possible beginnings of trouble in the years ahead.

Such signs of trouble are most apparent in certain departments—most particularly in the less distinguished departments and scientifically less distinguished universities. As the evidence will indicate, there has been a partial return to a pattern with fewer departments in a position to conduct research of the highest quality. However, even some strong departments are beginning to be affected.

Tendencies toward stratification differ among different fields. The adverse trends are generally more visible in departments that are ranked lower in the 1970 Roose-Andersen survey. It seems probable that the system is operating to sustain the relative strengths of the most eminent departments. The evidence from extensive interviews

and from data gathered from universities is unmistakable: In the past decade, strong departments have generally fared better than weaker ones in the competition for funding. Preeminent departments typically do not consider the level of federal research funding to be one of their most acute problems; among the less distinguished departments, decline in federal funding is often cited as a key problem. Data gathered from an American Council on Education-Rand sample of universities across various science fields confirm some of the trends observed in our site visits, reinforcing our general conclusions.[2]

Some anomalies, however, show up in the data, and many significant developments do not appear to be fully reflected. Aggregate data, for example, tell little about the distribution of foreign students among different categories of departments and different fields. This is particularly evident in physics: In at least six physics departments in our site visit sample, more than 40 percent of the graduate students were foreign. Without these students, the physics PhD programs in a number of departments would have suffered a very serious drop in enrollments, even greater than the general declines seen in national statistics. Although no firm data are available, it is our strong impression that foreign students are also important in fields other than physics, especially engineering, chemistry, and mathematics.

It is extremely difficult to assess the importance of the apparent tendency of the most strongly rated departments to increase their positions relative to those less highly rated. It is obvious that there are some overall signs of decline in certain fields (particularly in graduate student enrollments). An important question is, Will the system stabilize with fewer departments as significant research centers, or is an overall decline in process that will seriously affect the strongest departments as well?

Rapid changes in the environment for academic research are a notable feature in a number of disciplines, though such changes have received little notice, perhaps because institutions and departments have displayed a great deal of resiliency in adapting to new circumstances. It may appear on superficial inspection that a department has been moving along effortlessly in its established pattern—as measured by research support, graduate student enrollments, or general standing in the profession. This business-as-usual appearance, however, has often been achieved at the cost of strenuous efforts to maintain stability. One chemistry department at a public university, for example, showed a slight gain in federal funding for fiscal 1975, suggesting a steady growth in research funding. In fact, this increase was the result of a single new grant of a substantial amount, which disguised the fact that a number of smaller basic research grants had been terminated.

The biological sciences appeared to be in the position of tremendous expansion and enjoyed expectations for further growth. Yet just within

the last few years, a very sharp shift has occurred and the research environment has been greatly altered. A combination of several developments has abruptly halted the significant expansion that occurred from the end of World War II to the early 1970s: There have been sudden decreases in National Institutes of Health (NIH) training awards, in the NIH Research Career Development Award, and other federal programs. Universities have rather suddenly adopted the view that faculty size had best be closely rooted in educational missions rather than simply reflecting the availability of research funds.

The growth of medical schools and medical research centers has also rather abruptly ceased, cutting off career opportunities for many young biological scientists. Close observers of this field have in fact been surprised by the rapidity of change. The basic science (or preclinical) departments in academic medical centers are in particular flux, with sharp drops in graduate student enrollments and serious questions being raised about their future roles. What universities choose to do with respect to preclinical departments has in turn potentially wide impact on the biological science departments in the arts and sciences areas of the universities.

Changes have occurred in other fields as well, and with startling rapidity. As a converse example, enrollments in engineering schools, which were sharply off just a few years ago, have now surged forward in many universities, creating an abrupt shift in mood.

The emergence of large operating deficits at a number of private universities has also forced cuts in departmental expenditures. Plans for orderly departmental development can suddenly falter as the financial condition of the university deteriorates. In at least two of the major private universities visited, a protracted period of austerity, during which some progress was evident, was followed by a sudden surge of even larger deficits, significantly depressing the outlook for their science departments. A number of private universities kept tenure lines in the science departments unfilled; senior faculty disagreed about whether the departments would actually be permitted to make appointments or whether the lines existed only on paper.

There exist in brief, possibilities for sudden and rather dramatic program changes in research universities. Even the appearance of stability may be deceptive. A mosaic of forces affects the system—federal and state policy, the internal finances of the universities, career choices among the young, the economy, and numerous others—each of which exerts some influence on the total research environment. Changes in one or two variables may have a substantial impact, but it is difficult to predict such events with any confidence.

This new situation calls for careful observation. The conditions conducive to meaningful progress in the sciences could suddenly change if external adverse forces begin to exert serious influence. The gap be-

tween the first-rank and second-rank universities could also increase. Competition between universities would be significantly reduced if a large number of departments were to drop out of research. The quality of science in the remaining departments could also be affected, with the whole system undergoing rapid contraction. Yet vigorous competition among a slightly thinned number of science departments could, on the other hand, provide a stable system.

These uncertainties present policy makers with difficult choices. An overall issue of great national importance is whether the quality of American science can be sustained at its present high levels. Policy makers also need to concern themselves with the growing cautiousness of the entire science effort. Senior investigators in all science fields voiced concerns during our site visits that they and their colleagues were beginning to "play it safe" in this generally more austere funding environment, sticking to established lines of inquiry and taking fewer chances on novel and potentially high-payoff investigations that could fail. Does the slight decline in the U.S. share of world literature in various scientific fields reflect a potential loss of quality or the elimination of low quality publications? It is perhaps too early to tell. In the remaining part of this chapter, however, we attempt to give the beginning of an answer to questions about the quality and the state of academic science and engineering.

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1. National Science Board, *Science Indicators - 1974: Report of the National Science Board*, 1975 (Washington, D.C.: National Science Foundation, 1975), pp. 2ff; 50ff; 158, Table 1-6; 206, Table 3-20; and 207-208, Table 3-21.

2. Data in Table 3, page 93 (chemistry), Table 3, page 106 (physics), and Table 2, page 123 (mathematics) have been derived from NSF survey data on federally funded R&D expenditures in universities. The institutions included in the tables were selected from the 148 institutions in the American Council on Education-Rand sample used in Lyle H. Lanier and Ivars Zageris, *A Study of Financial and Educational Trends in Research Universities in Relation to Federal Funding of Health-Related Research: 1964-1974* (Washington, D.C.: American Council on Education, 1976). In Carnegie Commission categories, the original sample included 49 Research Universities I, 40 Research Universities II, 47 Doctoral Universities I, and 12 in other categories. Of the 148 institutions in the original sample, data on chemistry, physics, and mathematics expenditures for the years 1972-75 are available for 90 institutions. The institutions in the tables include most of the total number of institutions with ranked departments; for example, in chemistry, data on universities with 4 out of the 5 departments ranked 4.5-5.0 are included; 4.0-4.4, 6 out of 6; 3.5-3.9, 8 out of 8; 3.0-3.4, 16 out of 19; 2.5-2.9, 18 out of 20; below 2.5, 38 out of 67. Similarly high coverage was obtained in the tables for physics and mathematics. We are grateful to Ivars Zageris for his assistance in compiling and analyzing the data included in these tables.

A. CHEMISTRY

To some extent the once traditional divisions or subdisciplines of chemistry have eroded. Chemists, of course, still teach analytical, inorganic, organic, physical, and biochemistry. But the active research fields have changed, mirrored in part by the program structure within the Chemistry Division of the National Science Foundation. Structural, synthetic, and quantum chemistry now tend to cut across the older specializations. Interdisciplinary research at the borders of the older subdisciplines has become an important component.

Chemistry at the borderlines of traditional biochemistry, for example, is very much on the increase. This includes the use of important physical and analytical methods, the interaction between inorganic and organic chemistry that is reflected in molecules combining metallic and organic parts, crucial in biochemical systems. Advances in structural chemistry, quantum chemistry, and statistical mechanics are increasingly applied to complex biological systems.

In a related but separate area, surface chemistry and catalysis are opening new research vistas, from the surfaces of living cells to the synthesis of new materials. The old empirical techniques are now giving way to precise experimental studies and theoretical developments that will lead to new understanding of surface phenomena, one of the areas of chemistry most likely to lead to future applications.

In physical chemistry new techniques abound, such as the use of high-intensity, high-resolution laser light sources and new instrumentation in spectroscopy, which, combined with advances in theory, seem to be leading to a new understanding of excited states, transient molecules, and the interaction of light with matter. Chemists may soon be able to design a chemical system with a known set of desirable properties, and then design from purely theoretical and empirical knowledge an experimental method to produce it.

Laboratory data acquisition on a real-time basis, with complete backup computing networks, has become standard in most good laboratories. This research revolution continues to spread. Most chemistry departments now boast of literally dozens of minicomputers, microprocessors, and terminal access to larger systems. Chemistry continues to be an exciting science. There exist ample opportunities for shifts in research emphases as new discoveries are made, new equipment and techniques become available, and individual scientists discover fruitful new frontiers for investigation.

Nevertheless, within chemistry, the overall slowdown and changing emphases and patterns of research support have caused serious dislocations. During our site visits, the effects of the Mansfield Amendment upon synthetic organic, inorganic, and now nuclear chemistry were often mentioned, as was, in contrast, the generous funding of biochem-

istry. Analytical chemists have done well, though a number of departments no longer have analytical chemists on their faculties. The health of physical chemistry appears in need of special attention. The special needs of the various subfields is a less well-documented area, however, and judgments here must be considered tentative.

Trends in Research Funding

Unlike physics, chemistry has not suffered an absolute cut in current federal dollars. Nonetheless, research funding has not kept pace with inflation; federal obligations for chemistry R&D in universities and colleges declined by 14 percent in constant 1972 dollars between 1971 and 1975.[1] Moreover, the number of funding sources has declined somewhat, and fewer chemists are being supported. In current dollars, federal support for chemistry research and development in universities and colleges totaled $75.2 million in 1971, which increased to $85.6 million in 1975 (see Table 1). HEW (primarily NIH) and NSF each awarded more than $19 million in chemistry research grants to universities in 1971, and the funding of both agencies that year accounted for more than 50 percent of such research outlays. By 1975 the combined share of both agencies rose to 73 percent of all federally funded university research in chemistry. Between 1971 and 1975, DOD alone cut its funding for chemistry by almost a third, and the combined shares of DOD, NASA, and ERDA (AEC) dropped from 36 percent of the 1971 total to 23 percent in 1975.

As DOD, NASA, and ERDA have cut their sponsorship of chemistry research, investigators have had fewer outlets for their basic research proposals. With a funding system somewhat less pluralistic than in the past, chemists have increasingly relied on HEW (NIH) and NSF for research support. The Mansfield Amendment helped create an atmosphere in which the mission-oriented agencies began to reduce their support for broadly based basic science in favor of areas which could be more directly related to missions. An important consequence was the reduction of support given to synthetic and organic chemistry by NIH, and to inorganic chemistry by the various DOD agencies. A similar trend is now likely in ERDA with respect to nuclear chemistry.

Moreover, the strong increase in NIH support suggests growing attention to biomedically related chemistry research. For some chemists, this program interest creates incentives for researchers to modify their proposals so that work will appear to be health related. While the effects of such targeting on the discipline are difficult to gauge, some chemists fear a contracting funding environment for research that is not obviously related to disease and health. Site visit interviews reveal contrasting perceptions, however, as other chemists report no difficulty

Table 1

Federal R&D Obligations for Chemistry to Universities and Colleges, by Selected Agency, FY 1971-1975
(dollars in thousands)

YEAR	TOTAL	HEW	NSF	DOD	NASA	ERDA	USDA	EPA	Interior	Other
1971	75,215	19,255	19,089	12,833	5,777	8,711	5,457*	3,657	436	—
1972	77,588	23,627	25,308	14,311	4,429	7,241	679	379	1,555	59
1973	77,280	23,985	24,753	14,761	3,841	6,668	40	1,799	1,299	134
1974	83,157	29,803	25,424	8,826	3,466	6,755	618	4,607	3,491	167
1975	85,570	31,510	30,867	8,742	3,842	7,163	543	2,117	536	250

*Sharp fluctuations in the data can be explained by changing definitions of what constitutes chemistry research within an agency.

Source: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Years 1971-1975.* Annual publication (1975 in press).

in obtaining funds for research of their own choosing. Many chemists continue to believe that mission orientation leaves substantial room for the inventive scientist to seek out interesting research topics.

The grant acquisition process now requires much more time and effort than it did in the more affluent "boom" years. In the words of one chemist: "The days when a short and simple proposal could get funds are over." The recent experience of the NSF Chemistry Division proposals illustrates the heightened competition for funds.[2] Although NSF is only one among several agencies granting funds to chemists, its experience is important because of its commitment—alone among federal agencies—to support basic research across the subfields of chemistry.

In fiscal 1969 the Division received 660 proposals and funded 386 of these for a "success ratio" of 58 percent. Of 839 proposals received in fiscal 1975, however, only 286 (34 percent) were funded. The success ratio for new proposals declined from 31 percent in 1969 to 18 percent in 1975. In 1969, 287 out of 342 renewal proposals (83 percent) were funded; while in 1975, out of 450 renewal proposals, only 217 (48 percent) were funded.[3]

This tighter funding environment has raised the question of whether young investigators can succeed in the intense competition for grants. Some observers in fact suggest that high-quality young scientists no longer receive their fair share of available funding. In actuality, the NSF data suggest that young investigators (defined here as being no more than six years past the doctorate) are in some respects more successful in getting grants than established investigators. Renewing grants has become more difficult for both established and young investigators, but since 1970 the young have been more successful in getting renewal proposals funded. The renewal success ratio among established investigators dropped from 84 percent in 1969 to 47 percent in 1975; among the young it declined less sharply, from 82 percent to 58 percent over the same period. Figure 1 shows the same trend for new proposals. In 1969, 37 percent of new proposals by established investigators were funded; 11 percent were funded in 1975. However, the success ratio of the young was 26 percent in 1969, 17 percent in 1972, and 28 percent in 1975.

When both new and renewal proposals are considered, as in Figure 2, the data show that the young have improved their ability to get grants relative to established investigators. It is evident that the success ratio of established investigators has fallen more precipitously than that of young scientists. In 1969 the success ratio of established investigators (69 percent) was almost double that of young investigators (35 percent), but at 35 percent and 32 percent, respectively, the success ratios of both groups were almost equal in 1975. Perceptions of discrimination against the young in chemistry funding may thus be erroneous.

Statistical trends over the last five years indicate that fewer chemists are being supported by larger grants. While the number of NSF chem-

Figure 1

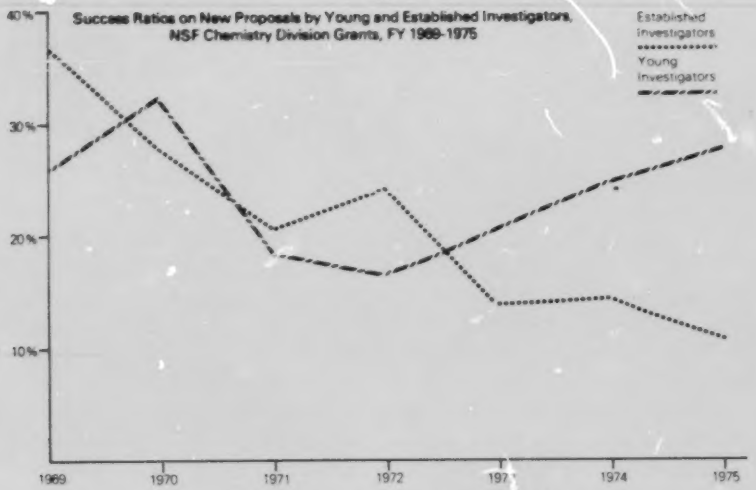
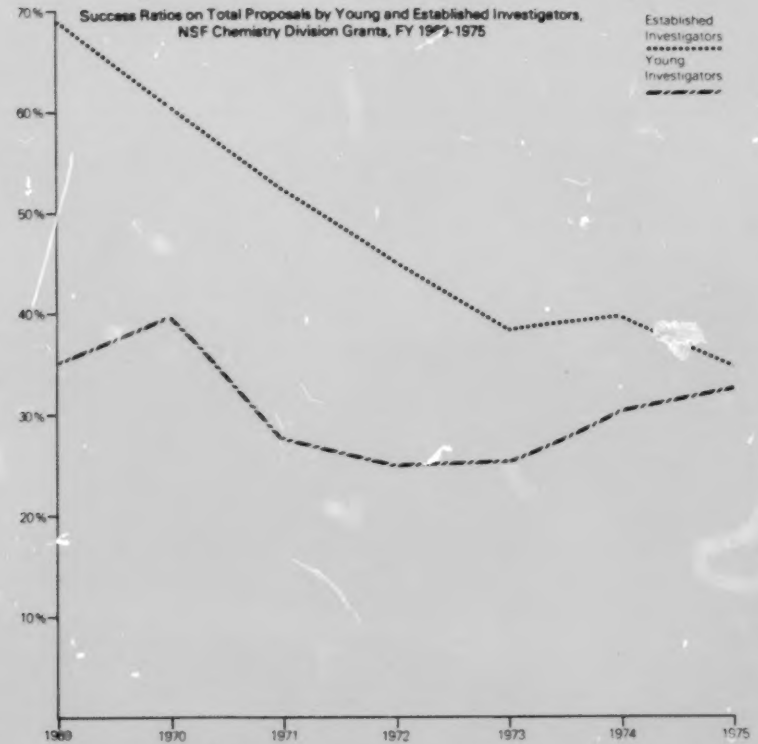


Figure 2



Source: Memorandum, "Data on Grants in the Division of Chemistry," January 19, 1976, NSF Chemistry Division.

istry grants has declined from 442 in 1970 to 286 in 1975, the median grant size in current dollars has been increasing. Table 2 indicates the trends in grant sizes for seven NSF chemistry programs. For example, the NSF Synthetic Organic program's annual median grant size per principal investigator has doubled from $17,900 in 1970 to $36,100 in 1975; in the Thermodynamics and Quantum programs, grant sizes increased by more than 70 percent over that period; and the grant size in the Chemical Dynamics program, which registered the smallest median increase, rose more than 40 percent from $19,900 in 1970 to $28,000 in 1975.

Although grant size and rate of growth vary from one subfield to the next, the overall trend across the programs is toward larger grant sizes. Again, however, such current dollar increases have suffered from inflation. Converted to constant 1972 dollars, such increases are more modest. For example, while the Synthetic Organic program's annual median grant size has grown by more than 100 percent in current dollars, the increase in real dollars is 45 percent.

Another trend indicated by the data is that the number of proposals decrease as success ratios decline. The NSF Chemistry Division received 939 proposals in 1971; that figure declined to 839 by 1975. It is interesting to note that most of this decline took place among proposals from young investigators. In fact, the number of proposals submitted by young investigators dropped from 235 or 29 percent of the total in 1970 to 191 or 23 percent in 1975. Over the same period the proposals submitted by established investigators increased from 577 or 71 percent of the total to 648 or 77 percent of the total.

Table 2
Median Grant Sizes for Programs in NSF Chemistry Division, FY 1970-1975*
(dollars in thousands)

Fiscal Year	1970	1971	1972	1973	1974	1975
NSF Chemistry Program:						
Synthetic Inorganic	18.0	21.4	22.1	26.0	28.7	32.5
Synthetic Organic	17.9	23.1	29.9	35.5	41.0	36.1
Structure	19.4	19.7	23.6	30.0	31.6	35.0
Quantum	20.1	23.5	24.8	30.0	36.3	34.6
Chemical Dynamics	19.9	20.3	27.6	27.0	27.1	28.0
Analysis	17.6	18.0	23.8	29.3	31.6	30.6
Thermodynamics	18.6	19.8	23.2	27.5	30.0	32.2

*Use of the median rather than the mean neutralizes the effect that a small number of large grants have on a single summary statistic. In the original data, grants (including grant amendments) have been "normalized" by conversion to a per-person, per-year basis. Supplements and conferences are not included.

Source: NSF Chemistry Division, "Grant Size and Funding Patterns for the Chemistry Division," Memorandum, March 26, 1976.

Several factors may account for this drop. Declining success ratios may have caused some young investigators to abandon the grant competition. Another important factor may be that fewer proposals come from the young simply because chemistry departments now have fewer young faculty. NSF data on 103 matched chemistry departments would apparently support this interpretation: In 1968, 34 percent of the faculty in these departments consisted of young investigators (defined for these data as those within seven years of the doctorate); by 1974, that proportion had dropped to 21 percent.[5]

Implications of a Tightened Funding Environment

The declining success ratios mean more intense competition for available funds. More time and effort also go into the process of seeking funds. Some scientists argue that this process of "grantmanship" has become an onerous claimant on time that might otherwise be used in research itself. However, more careful attention and effort in proposal writing more likely results in better science and more efficient use of limited resources. Although soliciting funds for research may interfere at times with the research process itself, it is doubtful whether higher standards in proposal consideration and declining success ratios have yet had the undesirable consequences some investigators have feared.

All available evidence clearly suggests an increased difficulty in securing NSF funds for chemistry research. The NSF survey of 103 chemistry departments indicates that the total number of faculty increased from 2,387 in 1968 to 2,555 in 1974. But this larger number of potential investigators now encounters an environment in which success ratios have declined, the number of grants has dropped (although grant sizes have increased), and proposals for renewals even from established investigators no longer carry the presumption of relatively assured success in funding. If the peer review process is working as it should, then high quality investigators should benefit, or at least should not suffer, in the increased intensity of competition. Some available evidence suggests that funding is in fact gravitating toward high quality researchers. The inferences we draw can be highlighted as follows:

> The highest ranked departments have apparently maintained or improved their funding shares relative to lower ranked departments.
>
> Within the strong departments sponsored research is becoming the province of a smaller number of investigators who are presumably more highly qualified than their colleagues who are not funded.
>
> A greater concentration of support (i.e., larger grant sizes) among the most highly qualified investigators has also appeared in the highest ranked departments.

In general, the impression gained by our site visits as well as our aggregate data analyses is that exceptionally productive scientists have increased their share of available federal grants, while those doing less distinguished chemistry research have either been denied support or have had their grants reduced.

Despite our own observations, the limitations of available data make it difficult to substantiate fully these assertions. For example, there is no national data series on research expenditures by individual departments. NSF does collect expenditure data by discipline, but they are based on funds expended by institutions rather than by departments. Accordingly, no precise statistics exist on the amount of funds spent by chemistry departments, as opposed to chemistry funds spent by other units in the university, although it is reasonable to assume that most reported expenditures are in fact spent by the departments. This complicates the task of determining how well departments of varying quality are doing in the funding process.

Data indicating the average amount of federally funded chemistry R&D expenditures in 90 universities by Roose-Andersen chemistry department ratings, for fiscal years 1972-75, are shown in Table 3. The average amount of such funds expended by each of four institutions with the very highest ranked chemistry departments (4.5-5.0) was $1.79 million in 1972, an amount that rose to $2.36 million in 1975. (Here again, the assumption is that all or most of these funds were expended by the respective departments of chemistry.) This was an increase of more than 32 percent, the highest proportional increase of all categor-

Table 3

Federally Funded R&D Chemistry Expenditures in Universities, by Roose-Andersen Chemistry Department Rating, FY 1972-1975, Average per Institution in Each Departmental Quality Category (dollars in thousands)

Roose-Andersen Rating	1972	1973	1974	1975	% Change '72-'75
4.5 - 5.0 (4 institutions)	$1791	$1877	$2017	$2366	32.1%
4.0 - 4.4 (6 institutions)	2077	2126	2080	2160	3.9
3.5 - 3.9 (6 institutions)	1194	1254	1305	1287	7.8
3.0 - 3.4 (16 institutions)	736	795	792	781	6.1
2.5 - 2.9 (18 institutions)	574	540	606	647	12.7
Below 2.5 (38 institutions)	246	260	252	277	12.6

Source: Derived from NSF Survey Data on Federally Funded R&D Expenditures in Universities. See footnote 2, page 85.

ies. (Seen in constant 1972 dollars, this top group of departments was alone among all categories in registering a net increase over the period.)

While institutions with lower ranked departments also registered increases in current dollars, it must be noted that these departments began with a smaller base, and relatively small absolute increases produce higher *rates* of increase. For example, institutions with departments in the lowest ranking (below 2.5) increased their chemistry expenditures by 12.6 percent. However, the absolute expenditure increase over the period averaged $31,000 in each of these institutions, while institutions with departments ranked 4.0-4.4 averaged absolute expenditure increases of $83,000 over the same period.

Findings from our site visits to chemistry departments suggest that the aggregate national data probably understate the increasing relative strength of higher ranked departments. For example, one distinguished chemistry department increased its federal funding 47 percent over the period—a sharper increase than was reported in the available national data. At the same time, lower ranked departments appear to have had greater difficulties in maintaining their federal funding than seems indicated by aggregate data. A department in the "good" category (2.5-2.9) reports that 10 faculty who regularly had grants five years ago are no longer able to obtain them. Eight years ago 12 of the faculty in a department ranked "adequate plus" (2.0-2.4) had grant support; only 3 are now funded.

Graduate Enrollment Trends

Funding is an obviously important factor in assessing the health of the research environment in a chemistry department. But the number and quality of graduate students serve as indicators as well. While federal funding for chemistry has been increasing slightly in current dollars, the number of graduate students in the discipline has declined. Annual production of chemistry PhDs has fallen from a peak of 2,223 in 1970 to 1,762 in 1975.[6] The total full-time enrollment in 168 matched chemistry departments has decreased from a peak of 13,720 in 1969 to 10,674 in 1975 (see Table 4). The total number of serious students in chemistry may be even smaller: Several departments reported that an increasing proportion of their students are in "holding patterns" en route to medical school.

The medical student syndrome deserves special attention. Almost a decade ago significant increases in undergraduate enrollments in chemistry occurred largely as the result of increasing interest in medicine as a career. By 1972, the American Chemical Society (ACS), citing an Association of American Medical Colleges survey, reported that "the number of undergraduates in premedical studies has increased about 20 percent from academic year 1970-71 to academic year 1971-72."[7] Of

Table 4

Total Full-Time Graduate Enrollment in 168 Doctorate-Granting Chemistry Departments, by Quality Category, Fiscal Years 1968-1975*

Roose-Andersen Rating	Enrollment, by Fiscal Year							
	1968	1969	1970	1971	1972	1973	1974	1975
4.0-5.0 (11)[a]	2359 (17.4%)	2368 (17.3%)	2308 (17.5%)	2151 (17.1%)	2012 (16.8%)	1906 (17.1%)	1896 (17.7%)	1927 (18.1%)
3.0-3.9 (26)	4005 (29.6%)	3955 (28.8%)	3749 (28.4%)	3461 (27.5%)	3246 (27.1%)	3101 (27.8%)	2911 (27.2%)	2807 (26.9%)
2.0-2.9 (41)	3733 (27.6%)	3763 (27.4%)	3576 (27.1%)	3476 (27.6%)	3353 (27.9%)	3086 (27.7%)	2885 (27.0%)	3023 (28.3%)
0.0-1.9 (44)	2014 (14.9%)	2032 (14.8%)	1946 (14.7%)	1937 (15.4%)	1836 (15.3%)	1644 (14.8%)	1553 (14.5%)	1536 (14.4%)
Not rated (46)	1453 (10.6%)	1602 (11.7%)	1615 (12.2%)	1553 (12.3%)	1551 (12.9%)	1405 (12.6%)	1458 (13.6%)	1318 (12.3%)
Total	13,564	13,720	13,194	12,578	11,998	11,142	10,703	10,611

*The percentages indicate the proportion of students enrolled in that quality grouping that year.

[a] The number in parentheses indicates the number of departments within the quality category.

Source: David W. Breneman, *Graduate School Adjustments to the "New Depression" in Higher Education* (Washington, D.C.: National Board on Graduate Education, 1975), Table 1, p. 19 and David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).

1,434 chemistry BS graduates responding to an ACS survey in 1975, 37.5 percent declared medicine, dentistry, or pharmaceutics as their field of further study, compared with 34.1 percent declaring chemistry.[8] Medical colleges have been unable to absorb all the students qualified to enter. Yet educational institutions have largely failed to recognize the seriousness of the problem and have done little to counsel students or to provide alternative programs for students unable to gain admission to medical schools.

One effect has been fierce competition among premed students for grades, disrupting undergraduate education. One department that we visited segregates bona fide chemistry majors from premeds to minimize such difficulties. Important consequences also seem to have followed for the graduate schools. Biochemistry graduate student numbers have increased markedly, but the observed effects of the "holding pattern" phenomenon include disinterest in research, an avid desire for good grades, and enrollment in courses relevant to medical school admission rather than biochemistry graduate work. And the dropout rate of graduate students subsequently admitted to medical school is often alarming (as high as 50 percent in the first year of graduate work).

Distinguished chemistry departments (ranked 4.0-5.0 on the Roose-Andersen scale) have slightly increased their proportionate share of graduate students over the last eight years as indicated in Table 4. In 1968, the distinguished departments enrolled 17.4 percent of all chemistry graduate students, a proportion that dipped to 16.8 percent in 1972 and has risen since then to 18.1 percent in 1975. These departments have been the only quality grouping showing a consistent increase in their proportionate growth since 1972; this is apparently the result of their generally maintaining the size of their overall enrollments, while enrollments have declined in lower ranked departments.

The changing patterns of graduate student support have contributed to the declining overall student numbers. The number of students supported by fellowships or traineeships declined from 3,846 in 1968 to 1,367 in 1975. Yet an increasing share of the graduate students receiving such support have gone to the distinguished departments: In 1968 the highest rated departments enrolled less than 25 percent of these students; by 1975 this had risen to 32 percent. Since NSF portable fellowships now comprise the largest graduate fellowship program, the "free market" choice of student award winners appears to result in a greater concentration of fellowship supported students in the distinguished departments.[9]

Moreover, while the total number of graduate student research assistantships in chemistry has declined from 3,370 in 1968 to 2,852 in 1975, the absolute number of students with such support in the distinguished departments has actually increased over this period. The distinguished departments increased their proportionate share of graduate student

research assistants from less than 20 percent in 1968 to almost 28 percent in 1975.[10] To the extent that research assistantship support coincides with federal research funding patterns, these statistics also suggest that the highest rated departments have increased somewhat their proportionate share of federal funding. While fellowship, traineeship, and research assistant support has become more concentrated in higher ranked departments, teaching assistantship support has become proportionally more important to lower ranked departments.[11]

As a result of these general trends, shortages of doctoral chemists could in time develop. As Harrison Shull summarized the evidence in his review of trends in chemistry for this study, "We are about to enter the same kind of supply-demand fluctuation in chemistry (and perhaps in other sciences) that has plagued engineering for a decade or more."

Summary of Site Visits

University chemistry departments exhibit great differences in size, quality, the ability to obtain research funds and good graduate students, the degree to which they specialize in the various subfields of chemistry, and the basic financial health of the institutions of which they are a part. Departments have had varying degrees of success in coping with the complex forces that have affected the university research environment over the last decade. The following section summarizes the differing impacts on different categories of departments visited. (The categories used generally correspond to the Roose-Andersen ratings unless otherwise indicated.)

Category A (five departments). The impressions gained by our site visits are consistent with the available data: The highest rated departments have proven most resistant to the threats posed to the university research environment. Departments in this category have either maintained or increased their research funding over the last several years, and they have continued to be successful in attracting first-rate graduate students. The chairman of one department declared, "We're stronger than we were five years ago." Another department, which is clearly vigorous, well financed, and of high morale, increased its federal support level by 47 percent between 1973 and 1975.

The distinguished departments tend to be superbly equipped with, for example, nuclear magnetic resonance spectrometers and other high-cost modern instrumentation. The graduate students are usually of excellent caliber. An investigator in one department was typical in his assessment of the graduate students in his department as "truly superior." Moreover, this same department received more graduate student applications for the 1976-77 academic year than at any time in the last 15 years. Significantly, all of the departments are able to hire new facul-

ty on a regular basis, even though the numbers of new hires are relatively few.

In terms of the inputs necessary for a topflight research effort—funds, students, and equipment—departments in this category have either maintained or improved their position over the last several years. Nonetheless, there is considerable concern, even in these superior departments, that indirect and long-term developments already in motion—including the weakening economic base of universities—may eventually damage their research environment if left unchecked. The supporting resources for research—facilities, equipment, technicians—are of particular concern.

Category B (eight departments). Five departments in this category were rated "strong" in the Roose-Andersen ratings and three were rated "good" or "adequate plus," though we believe the latter three have improved since the 1970 ratings. Support from federal sources runs about $1 million in each department. Though there has not been a dramatic decline in the vitality of the research environment in these departments, some indicators suggest that this group has experienced somewhat greater difficulty than the departments in Category A. Four have increased their funding levels and three have generally maintained their research support, while one has had a slight funding decline.

One department in this category has made a significant leap forward. It has one of the last new chemistry buildings in the country and one of the last NSF science development grants. Rather than expand its staff, the department decided to devote most of the science development money to instrumentation, thereby increasing the efficiency of the research efforts and offsetting the effects of the slight decrease of graduate students. But this is exceptional. Another department chairman in this group said: "We have reached the point where quality basic research is being adversely affected by inflation and by inadequate funding on the part of federal agencies and the state." Still another put the matter this way: "Our financial situation is adequate but fragile. The fundamental issue from our point of view is whether we keep up our momentum or slide back."

Declines in faculty and graduate students have varied in these departments. Two of them have suffered cuts in faculty, and five have fewer graduate students now than during the late 1960s. Noting the decreasing numbers of graduate students, three departments specifically complained of decreasing student quality as well. There are also indications among students of lowered morale, diminished enthusiasm, and a less serious commitment to the field—often attributed to the medical student phenomenon.

Category C (eight departments). These departments as a group have been more immediately affected by developments that have constrained their research efforts and threaten to undermine their quality. Problems

abound, including inflation, the perceived need for more graduate students, and increasing teaching assignments. In this group, the availability of equipment funds seems to have become significantly more limited. Instrumentation is becoming obsolescent. Here one also finds severe start-up problems for young faculty. In addition, practically no fellowships remain for students at these institutions.

One chairman declared that there is "no question that we're in bad shape. We were moving with our nose above the surface; now we're definitely going under." One third of the department's nonacademic staff has been removed, the undergraduate course structure has been hurt because of obsolete equipment, and about one fourth of the faculty is unsupported. Another department reports its research funding nearly doubled in the last five years, though a large share of this is accounted for by environmental and pollution work of an interdisciplinary and applied character. Some feeling exists that the "entrepreneurs" do better than people who toil away in one basic research area for a long period. Another department reports that while the cost of doing research has greatly increased, the university's contribution has decreased. The university has been unable to fill the gap resulting from termination of a science development grant. Meanwhile, the equipment deteriorates.

The student picture is disturbing. One department has gradually increased its number of graduate students by taking all "qualified" applicants (but there is a suspicion that standards have been compromised). In general, the situation of these departments is one of intense competition for graduate students, who are becoming harder and harder to recruit; graduate enrollments consequently tend to be slipping despite strenuous recruitment efforts. This decline has been especially evident in the last two years. For example, in three departments the number of graduate students has dropped by one third, one fourth, and 15 percent, respectively, as compared with the peak years of the late 1960s. Another department reports a substantial student shift toward biochemistry, with consequent high attrition rates and lack of interest in a research or teaching career. The departments that have either maintained their student numbers or slipped only slightly have done so by virtue of hard work, developing specialized programs tailored to specific needs, and by adapting to local job markets.

Category D (six departments). These six departments include one ranked by Roose-Andersen and five not ranked in the survey; the latter are partially representative of the more than 150 "other" doctoral-granting departments of chemistry. (As a group these five are probably above the average quality of such departments, but they have generally encountered substantial problems.) Two appear to be building up, two are relatively stabilized after sharp declines, and two have dropped significantly in research vitality. Much of their research funding is for ap-

plied work. Only a small proportion of the faculty have research support—usually those who have adapted their backgrounds and interests primarily to problem solving for mission agencies. A decline in graduate student numbers has also posed problems for these departments. One department, dissatisfied with its earlier strategy to abandon virtually all entrance standards, decided to admit fewer graduate students of higher quality and to hire more teaching postdoctorates in order to cover undergraduate teaching burdens. Another department considered the decline in the number of good graduate students as serious a long-term problem as that of declining federal funds.

Developments that constrain the research environment seem to have had the greatest impact on the departments in this category. Cuts in federal funding, declines in graduate student numbers, increasing difficulties in obtaining institutional support, and the pressures to do more applied work have touched these departments more than those in higher categories. While the outlook varies among the departments, funding and graduate student trends of the last five years have left their marks.

Supporting Resources for Research

Most chemistry departments have in some way been touched by a decline in the supporting resources for research, such as supplies, permanent equipment, and support personnel. Several departments also complained about space problems, which in fact may grow more acute as highly instrumented modern laboratories require more space than what used to be considered adequate.

Declines in support services pose immediate problems for chemistry departments. Although several departments reported forced cuts in research staff support—machinists, glassblowers, electronics technicians, and the like—the most critical need frequently mentioned was that of funds for equipment and its maintenance. Equipment bought in the affluent years is now either wearing out or is obsolescent. Capital expenses that should have been made in the intervening period were postponed because of the general budget crunch. For a number of years this delay made no significant difference, but now the problem has become urgent. As a chemistry instrumentation survey for NSF notes: "While funds are reasonably available for the purchase of glamorous state-of-the-art instruments, there is little provision for the replacement of workhorses (say, at the level of an A-60 NMR) when they wear out."[12] The very best departments are able to obtain the newest instrumentation, though even here problems of maintenance and replacement exist, and anxiety about the future persists.[13]

University chemists now do their research in an environment that has changed substantially over the last decade. Total funding has increased slightly when seen in current dollars but has declined in con-

stant dollars. Competition for funds has become much more intense. Success ratios on both new and renewal proposals have declined. The process of writing proposals has become much more laborious and time consuming. A decrease in the number of risk-taking proposals is one ostensible consequence of this new constrained funding environment.

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1. The implicit GNP price deflator was used to convert current dollar totals in Table 1 to constant 1972 dollars. See Figure 2. Chapter II, p. 18.
2. NSF Chemistry Division Director Jack B. Kinsinger has kindly provided the data on which the following discussion is based.
3. NSF Chemistry Division, "Data on Grants in the Division of Chemistry," Memorandum, January 19, 1976. The data exclude conferences, withdrawals, supplements, and amendments to continuing grants.
4. Ibid.
5. *Young and Senior Science and Engineering Faculty, 1974: Support, Research Participation, and Tenure*, NSF 75-302 (Washington, D.C.: National Science Foundation, 1975), Table B-7, p. 23.
6. National Research Council, Commission on Human Resources, *Summary Report, 1975: Doctorate Recipients From United States Universities* (Washington, D.C.: National Academy of Sciences, 1976), Table 1, p. 12. Data for 1970 derived from 1970 *Summary Report*, p. 4.
7. "Starting Salary Survey" (Washington, D.C.: American Chemical Society, 1972), pp. 2-3. Mimeographed.
8. American Chemical Society, Office of Manpower Studies, *1975 Survey Report: Starting Salaries and Employment Status of Chemistry and Chemical Engineering Graduates* (Washington, D.C.: American Chemical Society, January 1976).
9. David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).
10. Ibid.
11. Ibid.
12. Cheves Walling, et al., *A Study to Improve the Management of Costly Instrument Centers: A Report to the National Science Foundation* (Salt Lake City: Department of Chemistry, University of Utah, n.d.), p. 60.
13. See Chapter V for an extended discussion of supporting services for research.

B. PHYSICS

Exciting and vital developments in physics are appearing at a time when external indicators suggest a potential decline in the research effort. There have been dramatic discoveries in particle physics within the past three years. Findings of "very massive and relatively long-lived" new particles at SLAC (Stanford Linear Accelerator Center) and Brookhaven lead many physicists to believe "that the discoveries may have opened a whole new dimension in the world of subnuclear particles, analogous to finding the first of many so-called strange particles in 1947."[1] Stanford Linear Accelerator Center Deputy Director Sidney D. Drell has called recent discoveries "the most startling and exciting to emerge from high-energy physics in a decade or more."[2] Physicists have high expectations of what the very near future may hold.

Research advances in the field of nuclear science also seem to be proceeding rapidly. A National Academy of Sciences (NAS) report on nuclear science declares:

> It cannot be emphasized too strongly that the task of understanding the basis of nuclear science is as intellectually exciting and challenging as it has ever been, with major discoveries—deep inelastic interactions, regularities in very high angular momentum states, giant quadrapole modes of nuclear oscillations, discoveries of exotic nuclei—occurring at least as frequently as they ever did.[3]

In a broad assessment, Professor Chien-Shiung Wu, retiring president of the American Physical Society, declared in 1976 that "American physics is strong and vital and holds leading positions along nearly all of its frontiers. For some fields of physics, certainly for particle physics, the year just past has been exhilarating. But American physics in general seems to hustle along with...enormous vigor and success...."[4] NAS President Philip Handler conveys the same sense of potential in his report to NAS members:

> Day by day, here at the Academy, I am aware of the excitement attendant upon what appears to be an elaboration of a new chapter in elementary particle physics and the great potentialities offered by the ability to deal with heavy ions, of the advances in high resolution spectroscopy made possible by newer types of lasers, of the possibilities opened by expanded understanding of the properties of catalytic surfaces, of the potential, for material science, of the new ability to prepare metal glasses, of the building interest in synchrotron radiation sources and their possible uses.[5]

Despite such substantive research advances, other indicators, such as funding for research and facilities, graduate student enrollments, PhD production, and unbalanced faculty age distribution, point to a contracting research environment for physics in the years ahead.

Trends in Research Funding

The contributions of physics research to the technological advances made during World War II helped to make physicists the most successful claimants of federal research resources during much of the postwar period. Physics research was substantially, if indirectly, tied to the national defense effort. During the 1960s, however, changes in R&D funding policies of the Department of Defense, coupled with growing support for life sciences research, contributed to a dramatic shift in the favored position physics had enjoyed. Federal R&D obligations to universities and colleges for physics dropped from $155 million in 1971 to less than $150 million by 1975 (see Table 1). In constant 1972 dollars, this constituted a decline of 27 percent.

In addition to the decrease in total federal funding for physics research in universities, the mix among agency sponsors of such research has also changed. As Table 1 indicates, DOD and NASA have decreased their funding for physics research in universities, while NSF and ERDA—together accounting for 69 percent of physics funding—now lead the field as the largest sponsors of such research. Between 1971 and 1975, NSF funding for university physics increased from $30 million to $52 million; combined DOD/NASA funding declined from $74 million to $44 million. NSF's relative share of university physics funding increased from 19 percent to 35 percent; DOD's declined from 32 percent to 19 percent.

To some degree, the data in Table 1 understate the importance of the Energy Research and Development Administration to university physicists, since ERDA funding of university-managed FFRDCs is not included in the figures. However, as the research into increasingly smaller particles of matter requires larger and more sophisticated equipment, university physicists must travel to regional or national centers to carry on their experiments. These centers include such ERDA-funded FFRDCs as the Argonne National Laboratory, the Brookhaven National Laboratory, the Fermi National Accelerator Laboratory, the Holifield National Laboratory (Oak Ridge), the Lawrence Berkeley Laboratory, the Los Alamos Scientific Laboratory, and the Stanford Linear Accelerator Center. Despite a slight decrease between 1974 and 1975, ERDA support for university-administered FFRDCs has increased more rapidly than its support for university physics research; its obligations to FFRDCs grew from $452,816 to $616,937 over the 1971-75 period.[6]

The generally tighter funding environment for physics research is reflected in the constraints in various subfields. The 1975 NAS report on nuclear science indicates that "the total federal support for basic nuclear physics was reduced by some 23 percent, from $72 million in FY 1969 to about $55.5 million [1969 dollars] in FY 1973."[7] Moreover, the

Table 1

Federal R&D Obligations for Physics to Universities and Colleges, by Agency, FY 1971-1975
(dollars in thousands)

Year	Total	NSF	DOD	NASA	ERDA	HEW	EPA	Interior	Commerce	Other
1971	155,219	30,135	50,389	23,744	48,548	439	50	1,399	515	–
1972	141,626	45,384	35,675	16,321	42,863	248	281	682	165	27
1973	140,249	46,286	32,842	18,016	41,966	453	293	224	124	46
1974	131,625	48,891	20,979	15,416	45,042	493	410	97	165	132
1975	149,835	51,792	29,018	15,369	52,093	701	429	14	140	279

Source: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions*, Annual Publications, Fiscal Years 1971-1975 (1975 publication in press.)

number of active facilities for nuclear research has been cut from 90 in 1969 to approximately 65 in 1973, and "about 25 percent of the remaining active facilities [facilities ranging from modest 4-MV accelerators to large cyclotrons and tandems] are being run at less than full levels of operation and at reduced efficiency because of the lack of adequate support, which is translated into inadequate staffing, termination of postdoctoral positions, inadequate electronic instrumentation and computer hardware and the like."[8]

Similarly, a 1974 report prepared by the AEC Subpanel on the Health of High Energy Physics declared that the real support of high energy physics research declined by approximately 20 percent between 1969 and 1974.[9] The Cambridge Electron Accelerator, the Princeton-Pennsylvania Accelerator, and the California Institute of Technology Synchrotron have been closed down, and the Bevatron at Berkeley has been converted from a facility for elementary particle physics research to one for nuclear physics research. While funding for the National Accelerator Laboratory has increased, support for other high energy facilities has declined. Total personnel in the high energy physics program has declined by 25 percent since 1969, the total number of operating shifts has decreased, and, according to the AEC report, "The total number of experiments completed per year has dropped greatly since 1970."[10] Although high energy physics research has recently witnessed some spectacular developments, these indicators suggest that a cautionary note for the future would be advisable; the total effort may lose momentum.

As in chemistry, funds for equipment in physics have shown a decline (although this is sometimes hidden in the general decline in most aspects of physics funding). There has been a declining trend of permanent equipment funds in NSF-funded research generally. The general trend appears to reflect accurately the developments in physics: Of all the expenditure items, permanent equipment funds have shown the sharpest declines. In fact, the amount of resources spent on permanent equipment per senior personnel man-month has declined by almost 65 percent between 1968 and 1974.[1]

More intense competition for available support, in physics as in chemistry, has resulted from the generally tighter funding environment. ERDA funds awarded for new research projects declined from $6.1 million in 1965 to $0.7 million in 1972, but with a rise to $2.4 million registered by 1975 (see Table 2). The number of research requests declined from a 1969 peak of 417 to a low of 200 in 1972. Although the last three years show increases in the number of proposals and the amount of support awarded, the funding environment has clearly tightened since the mid-1960s.

The extent to which tightened support patterns have affected different types of physics departments is difficult to analyze. The assump-

Table 2
Disposition of Funding Requests for Research Projects
ERDA Division of Physical Research, FY 1965-1975 (dollars in millions)

Fiscal Year	New Proposals Received During Year Amt. (No.)	Approved Amt. (No.)	Not Approved Amt. (No.)	Terminations Amt. (No.)	Total No. of Contracts in Force at End of Year Amt. (No.)
1965	$32.9 (336)	$6.1 (60)	$25.0 (276)	na	na
1966	33.8 (366)	5.1 (58)	39.9 (331)	$1.4 (54)	$66.4 (505)
1967	42.1 (391)	3.2 (56)	16.2 (292)	0.9 (41)	71.0 (516)
1968	41.7 (358)	2.2 (58)	36.4 (356)	1.5 (48)	71.1 (525)
1969	42.3 (417)	2.6 (76)	41.8 (270)	1.2 (58)	71.1 (543)
1970	46.6 (412)	1.5 (31)	68.7 (421)	2.1 (59)	68.5 (515)
1971	14.4 (326)	0.9 (18)	14.6 (321)	1.5 (40)	61.7 (484)
1972	8.[illegible]00)	0.7 (21)	11.5 (205)	9.8 (142)	50.2 (368)
1973	11.1 (222)	0.9 (21)	8.5 (214)	2.5 (57)	51.1 (330)
1974	15.1 (301)	1.0 (20)	11.9 (226)	1.5 (30)	52.2 (315)
1975	23.7 (365)	2.4 (51)	17.4 (306)	1.0 (27)	55.6 (332)

Source: Energy Research and Development Administration, *Physical Research Program: Research Contracts and Statistical Summary*, ERDA—63-75, July 1, 1975, p. 12-13. Data for fiscal year 1965 were taken from the 1974 publication, p. 13.

Table 3
Federally Funded R&D Physics Expenditures, by Roose-Andersen Department Rating, FY 1972-1975, Average per Institution in Each Quality Category (dollars in thousands)

Roose-Andersen Rating	Fiscal Year 1972	1973	1974	1975	% Change '72-'75
4.5-5.0 (5 institutions)	$3732	$3701	$4059	$4116	10.3%
4.0-4.4 (4 institutions)	3292	3312	3352	3390	3.0
3.5-3.9 (8 institutions)	2590	2891	2868	3095	19.5
3.0-3.4 (11 institutions)	1350	1680	1699	1485	10.0
2.5-2.9 (18 institutions)	972	1041	956	977	.5
Below 2.5 (44 institutions)	308	362	377	353	14.6

Source: Derived from NSF Survey Data on Federally Funded R&D Expenditures in Universities. See footnote 2, page 86.

tion that the major share of reported physics R&D expenditures are, in fact, spent by physics departments is less valid here than in chemistry, since a considerable amount of physics funding may be presumed to go to engineering departments. Moreover, there was a wide discrepancy between the expenditures that appear in NSF data and those observed in site visits to physics departments. One complicating factor is the difficulty of determining the effects of the affiliated laboratories on departmental research efforts, since the grant totals for these laboratories do not show up in the NSF data series used in our computer runs. We present the data in Table 3 with less than total confidence in its ability to reflect accurately the complex realities of physics support.

The average amount of federally funded physics R&D expenditures in 90 universities by Roose-Andersen physics department ratings for fiscal years 1972-75 are shown in Table 3. Universities with the very highest ranked departments increased their federal R&D physics expenditures by 10 percent between 1972 and 1975, while those ranked below 2.5 increased their expenditures by more than 14 percent over the same period. Such rates of increase should be viewed with care, however, since the base from which such increases are measured differs widely among the categories of institutions. For example, over the period the average absolute increase in physics expenditures in the highest ranked institutions ($384,000) was more than eight times greater than the average absolute increase in such expenditures in the lowest ranked institutions ($45,000). Moreover, beginning in 1973, there appears to be an upward funding trend in universities with higher ranked departments and a downward trend in those with lower ranked departments.

Trends in Graduate Student Enrollment

The tightened funding environment in physics has been accompanied by a contraction in its graduate student pool. Annual PhD production in physics and astronomy has fallen from a peak of 1,740 in 1971 to 1,293 in 1975.[12] Total full-time graduate enrollments in 146 matched physics departments declined from 11,163 in 1969 to 7,743 in 1975 (see Table 4). However, while the total has decreased, the "distinguished" departments (rated 4.0-5.0 on the Roose-Andersen scale) slightly increased their proportionate share of graduate students, from 18.4 percent in 1969 to 20.8 percent in 1975; the "strong" departments (3.0-3.9) also registered a slight increase after 1973. Lower ranked departments (2.0-2.9) decreased their share from 29.6 percent in 1969 to 24.8 percent in 1975; and the lowest ranked departments (0.0-1.9) also registered a slight proportionate decrease over the period.

The stronger relative position of the highest ranked departments is further demonstrated by data on the various forms of graduate student support: Although the total number of fellowships and traineeships has

declined dramatically from over 2,700 in 1968 to less than 900 in 1975, the distinguished departments have increased their proportionate share over the same period. In 1968, fewer than 25 percent (or 681 out of 2,772) of all fellowships and traineeships went to graduate students in the distinguished departments; by 1975, these departments increased their share to more than 37 percent (or 310 out of 835), but they still had fewer than half as many graduate students with fellowships and traineeship support than was the case in 1968.[13]

A similar trend has been taking place in research assistantship support. While the total number of research assistantships in physics has declined from more than 4,016 in 1968 to 2,734 in 1975, an increasing proportion of available research assistantships has been going to graduate students in the distinguished departments. In 1968, less than 24 percent of all graduate students supported by research assistantships were in the distinguished departments; this rose to almost 31 percent by 1975.[14] The most striking feature about recent trends in graduate support is, however, the sharp overall decline, which clearly has contributed to declining physics graduate enrollments.

Evolving Manpower Trends

The difficulty young physicists now face in getting tenure track appointments in academic institutions and the sharp drop in graduate student numbers are the two manpower trends with serious implications for the discipline. A recent NSF study reports that the proportion of young faculty (defined as being within seven years of the doctorate) in 77 physics departments has dropped sharply from 38 percent in 1968 to 18 percent in 1974.[15] In fact, of the 12 disciplines covered by the study, physics alone experienced a cut of more than 50 percent in the proportion of young faculty. The relative leveling off in physics faculty sizes in the 1968-74 period has left fewer academic openings for young physicists; the situation in physics is perhaps the most severe in this respect among the various physical sciences.

According to the NSF study, 77.7 percent of all faculty in physics departments studied had tenure in 1974. While tenure ratios seem to have generally increased, some interesting differences appear among departments. Within the "distinguished" or "strong" Roose-Andersen physics departments, for instance, one is almost 97 percent tenured, while another has a tenure ratio of less than 40 percent. In private institutions the average ratio for physics departments is 70.9 percent compared to 81 percent in public institutions.[16]

As shown in Figure 1, the proportions of assistant professors and instructors/lecturers have dropped sharply in 100 matched PhD physics departments since 1960. At the same time, the proportion of associate professors has remained relatively stable; only the proportion of pro-

fessors has increased significantly. The data reflect the sharp drop in the number of new hires in physics departments.

The Ad Hoc Panel on Manpower and Education for the NSF report on nuclear science declared: "In fall 1968, between 1,100 and 1,200 new faculty were hired by some 700 physics departments; most such hiring represented expansion of staff, not just the filling of vacancies created by retirement and the like. In fall 1973, only half that number was hired, most for the replacement of junior faculty."[17] Moreover, as the academic job market tightens, fewer junior faculty who leave departments remain in universities. MIT physicist Lee Grodzins, a close observer of physics manpower trends, sums up the situation as follows:

> The precipitous declines in the outside hires at the Associate and Professor levels, and the correlated drop in retention factors in academia for those leaving their departments, signal the end of an era. For decades, the emerging physics departments in the country staffed their faculties as much through outside hires as from internal promotion. Now there is saturation in the sizes of most departments; very few can be called emerging. The opportunities in academia for those denied tenure have shrunk alarmingly. And this erosion in opportunity affects even those from the most distinguished departments....[18]

Though he is careful to point out that those who have left university research careers may not have actually left the discipline, Grodzins concludes that "from the point of view of the vitality of academia itself, one must question whether we can afford a loss of a good fraction of our most able scientists."[19]

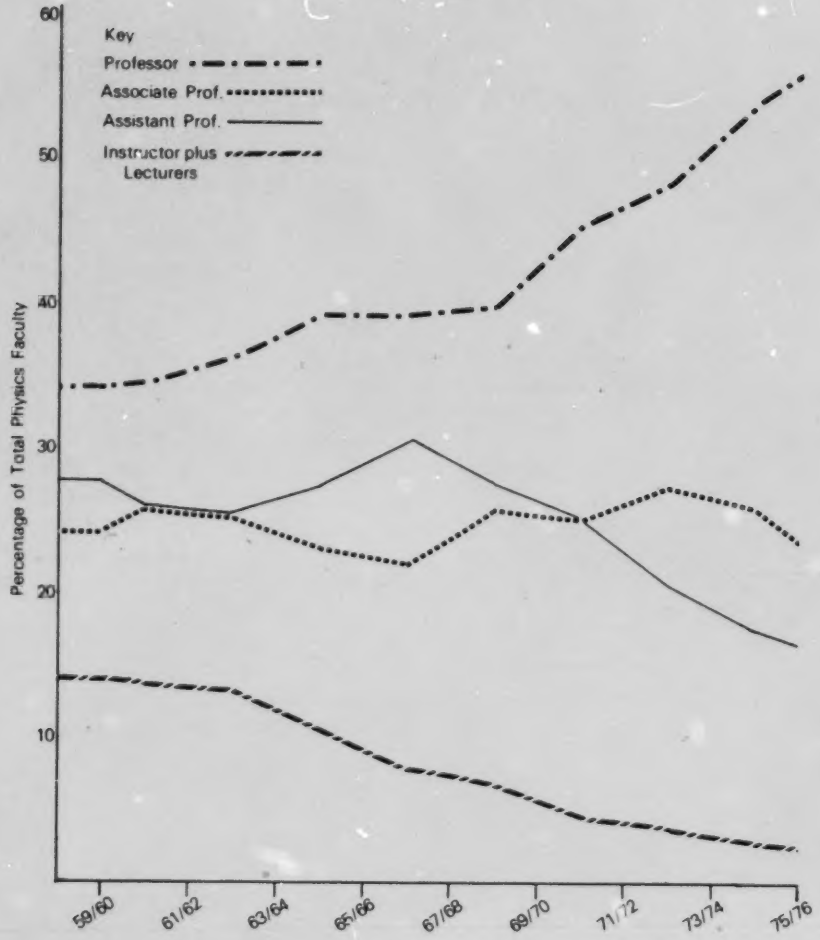
The decreasing proportion of young faculty suggests that most departments can no longer rely as before on new talent bringing fresh ideas to departmental research efforts. Moreover, the prospect of few new openings in physics departments may discourage high quality graduate students and recent PhDs interested in pursuing a university research career. Most PhDs can get some kind of position immediately after they receive the degree. However, many of these positions tend to be temporary teaching or postdoctoral research appointments. The real constriction in the pipeline comes during the search for the second job or for a position on the tenure ladder. Job seekers faced with the prospect of a "holding pattern" in a series of postdoctoral and/or temporary teaching appointments may simply abandon pursuit of a university research career.

Summary of Site Visits

All physics departments have in some way felt the effects of a tighter funding environment and a declining graduate student pool; a high ranking in 1970 is not necessarily a guarantee of a department's success

Figure 1

Faculty Distributions in 100 Matched PhD Physics Departments



Source: L. Grodzins, "Changes in the Distribution of Physics Faculties in the United States, 1959 to 1975," May 1976.

Table 4

Total Full-Time Graduate Enrollment in 146 Doctorate-Granting Physics Departments by Quality Category, FY 1968-1975*

Roose-Andersen Rating	Enrollment, by Fiscal Year							
	1968	1969	1970	1971	1972	1973	1974	1975
4.0-5.0	2,106	2,059	1,998	1,855	1,691	1,593	1,579	1,608
(10)a	19.1%	18.4%	18.7%	18.5%	18.4%	19.1%	20.3%	20.8%
3.0-3.9	2,896	2,906	2,727	2,462	2,294	2,028	1,893	1,950
(19)	26.2%	26.0%	25.5%	24.6%	24.9%	24.3%	24.3%	25.2%
2.0-2.9	3,274	3,307	3,165	2,805	2,493	2,261	2,086	1,922
(39)	29.4%	29.6%	29.6%	28.0%	27.0%	27.1%	26.8%	24.8%
0.0-1.9	1,537	1,523	1,429	1,457	1,311	1,169	1,059	1,052
(41)	14.2%	13.7%	13.4%	14.6%	14.3%	14.0%	13.6%	13.6%
Not rated	1,230	1,368	1,362	1,432	1,421	1,289	1,171	1,211
(37)	11.1%	12.3%	12.8%	14.3%	15.4%	15.5%	15.0%	15.6%
TOTAL	11,043	11,163	10,681	10,011	9,210	8,340	7,788	7,743

*The percentages in each of the cells indicate the proportion of students enrolled in that quality grouping that year.
[a]The number in parentheses indicates the number of departments within the quality category.

Source: David W. Breneman, *Graduate School Adjustments to the "New Depression" in Higher Education* (Washington, D.C.: National Board on Graduate Education, 1975), Table 5, p. 23 and David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).

in coping with new environmental forces. Nevertheless, the available data and site visit impressions indicate that more highly ranked departments have either generally held their own or slightly improved their position relative to lower ranked departments.

Category A (six departments visited). These departments, ranked in the 4.0-5.0 or "distinguished" range of the Roose-Andersen ratings, have maintained their traditional high quality research efforts. One chairman declared that his department has "been extraordinarily successful in research over the last three years." His department has had 6 to 10 very successful projects. "I would have been happy with any one of these," he said.

These departments have not been immune, however, to threatened constraint in the future research environment. Ensuring the flow of young research talent into the system—and nurturing that talent—is a concern shared by most of them. As expressed by one chairman, the real problem is "the inadequate support of nontenured experimental physicists who are not under the umbrella grant of a senior physicist. The scarcity of federal dollars is particularly hard on younger faculty. Assistant professors are under tremendous pressure to produce research results in an environment where the resources necessary to establish reputations as an independent investigator are harder to obtain."

The drop in the number of graduate students is of concern even in departments at this level. One chairman indicated that there used to be more qualified students than the department could admit. Now there has been a 30 percent (self-imposed) cutback in graduate students; fewer students are highly qualified. For another department, admitting fewer students has complicated life for certain experimental groups that use graduate students in research. Still another department has also experienced some difficulty in getting postdoctoral applicants because PhDs have increasingly gone to industry or national laboratories rather than struggle at a postdoctoral level and hope for an academic opportunity.

But perhaps the most serious potential danger is the tendency to "play it safe" when funds are tight. One chairman summed up the problem by noting that "it has always been difficult to get new projects started, but the situation is now much worse, particularly if the research area is 'different.'" Among other manifestations of the "play it safe" tendency is the increasing reluctance of some graduate students to take risks; they prefer a safe thesis topic that will be more likely to lead to a certain job.

Though none of the distinguished departments visited has suffered drastic cuts in project funding, each identifies one or more of the following threats to its research effort over the long run: inflation, rising indirect cost rates, less flexible funding, constraints on university re-

sources, a smaller number of high caliber graduate students, increased scarcity of tenure slots, and the slackening flow of young people and new ideas into the research system. The net result, in the words of one chairman, is a "creeping conservatism [and other] serious problems which don't show up in the dollars."

Category B (nine departments). The nine departments visited in this category, rated "strong" in the Roose-Andersen ratings, have had varying success in maintaining their federal support levels. Two have increased their funding; three have held steady; three have registered slight declines; and one has lost two umbrella contracts resulting in a sharp drop in overall support. In addition, two departments have lost support for medium-energy facilities. These departments generally have not suffered drastic cuts in project support, but in several cases the research efforts have lost some momentum. In one instance, almost one fourth of the faculty did not have and was not actively seeking funds. Three other departments report that their theoretical physics programs have experienced reduced support.

Only one department in this category appears to have any realistic prospect of growth in the number of regular tenure appointments available over the next decade. Most other faculties are either in a steady state or decreasing slightly; they have relatively high tenure ratios, with staff size generally frozen and with the ability to fill vacancies somewhat uncertain. However, the problem that seems to concern these departments most is the sharp reduction in the number of graduate students. When its number of graduate students fell by 50 percent, one department converted itself into a semi-institute style of research operation, relying heavily on postdoctoral researchers and technicians to replace the students. There is some indication that a decline in the quality of students has occurred as well. The problem is not so much the number of graduate students as their motivation and productivity.

Three other departments in this category are making greater use of postdoctoral appointments. The smaller number of graduate teaching assistants has adversely affected undergraduate programs. Undergraduate class sizes have increased. According to one chairman, "We're not doing as much correcting of undergraduate papers." With the decline in graduate student numbers, some of these departments are increasingly pressed to justify their faculty sizes. Reflecting on the relation between enrollment and state funding in public institutions, one department chairman declared, "I'm more worried about the loss of state support. We bring in people on a mix of state and contract money, and if we don't have the state base, we're in trouble."

While the research effort continues to be vital in most of these departments, forces in motion are cause for concern. "We have not suffered in many major ways," said one chairman, "because we've lived off capital—but the end is in sight." In sum, the departments in this cate-

gory share in the kinds of problems affecting Category A departments. However, the degree of stress here appears to be somewhat greater.

Category C (seven departments). These departments are ranked in the "good" and "adequate-plus" ranges in the Roose-Andersen ratings. Several departments in this category have either maintained or increased their total research funding. One department in this category has a total federal research support level of $4 million and another department has slightly increased its federal support over the last five years. But funding cuts have begun to threaten seriously the research effort in at least three departments in this category.

The experiences of two of these departments are illustrative. The total sponsored research effort in the first department has declined by 50 percent from a peak of $200,000 annually in the late 1960s; approximately half the faculty members have no grants. The lack of funds has had at least two consequences: First, graduate students cannot be supported on research assistantships; second, the department cannot buy major pieces of equipment (it must rely on its own ability to build them). The funding trend now is slightly up with an emphasis on short-term applications, particularly in plasma and fusion physics. Some belt tightening is fine, but, according to the chairman, "We are past the point where cutting is good."

In the second department there are multiple signs of serious trouble. Research funds have dropped by more than 40 percent since 1967, and eight young tenured faculty have dropped out of research. General demoralization is evident in the department. Although a few subfields have active researchers, the younger ones "can't get their own contract support." Graduate enrollments are down, the department is 96 percent tenured, and there is little or no prospect for new appointments. Summing up, a senior faculty member said, "We're in a real jam."

A pervasive problem affecting these departments is the lack of graduate students. The problem is illustrated by the experience of one department that has increased its funding level but now faces the problem of justifying the size of its faculty, which is too large in relation to its student enrollment. The department is having difficulty getting enough students and especially getting a sufficient number of good students; the number of postdoctoral fellows is increasing, but on "soft" money. In another department, PhD candidates have dropped by 50 percent, and concern is expressed about the possibility of an additional 50 percent drop, which would have serious implications for the number of teaching assistants allotted to the department.

None of the departments in this category has been untouched by the forces that tend to restrict research efforts. Those departments maintaining their funding levels have had difficulty getting good graduate students in sufficient numbers. Other departments have begun to experience severe difficulty in getting research grants. Four departments

report that fewer of their faculty members now have grants compared to the peak funding years of the late 1960s. Three of these departments specifically noted a difficulty in getting funds for theoretical research. Moreover, three departments pointed to severe difficulties in getting and maintaining equipment for research purposes.

Category D (six departments). These departments, ranked below 2.0 on the Roose-Andersen ratings, have had varied success over the past decade in coping with the forces affecting research. In one department, federal funds have more than doubled since 1969; however, some faculty members do not have outside funding, and no new appointments are likely since the department is fully tenured. In another department, research funding is down by more than 80 percent; only one significant grant remains. Graduate student enrollment is down by 40 percent, and the department produces only one PhD per year. The department essentially no longer considers itself a research operation, and there is now more focus on undergraduate teaching. Class sizes in the graduate school are relatively small, and some advanced courses are simply taught less frequently. The number of faculty in another department has been cut by almost half, and in still another the enrollment is down to the point where the department is advertising for students in foreign countries.

The foreign student factor is important not only in these departments, but in Category B and C departments as well: Many such departments are greatly aided by a large influx of foreign students. In fact, some departments reported foreign graduate enrollments as high as 40 to 60 percent of the total graduate enrollment.

Several departments in this category have described their research efforts as substantially applied in orientation. One chairman characterizes less than 40 percent of the research grants in his department as "pure research." He sees an even stronger move to applied physics because of student movement in this direction. Another department with substantially increased funding over the past several years has more of an applied orientation now than it did five years ago. According to the chairman, not much difference remains between the engineering and physics departments. To bolster enrollments, another department has included an applied physics option in its undergraduate program.

Some departments in this category have been successful to the degree that they have become increasingly selective in their research efforts. One department does not try to cover the whole spectrum of physics; rather it emphasizes materials and solid state research. Another specializes in atmospheric physics. Two specifically cited a deliberate move to applied research. Most of the departments in this category have been touched by one or more of the factors altering the research environment, including declines in graduate student numbers and a drop in research funding. A number of these departments will

probably suffer a further and potentially sharp research contraction if current trends continue.

Other Developments

Most major physics laboratories have some type of research appointment, based on grant and contract funds, which is outside the regular tenure promotion ladder. The numbers vary from institution to institution, and the degree of institutionalization may differ, but this development could be of increasing significance. How the system works is illustrated by the experience of one department: The new PhD may be brought in as a research fellow; after a year, or at most two, he or she becomes a research staff physicist (the parallel faculty position would be instructor); next comes the research associateship (parallel to the assistant professorship); then senior research associateship (roughly similar to the associate professorship); and finally the senior research physicist (parallel to the professorship). Occupants of these positions have virtually all the privileges of the equivalent faculty appointments, except they do not vote on new appointments. The two most senior positions, those of senior research associate and senior research physicist, have "rolling tenure" so that at any given instance the university is committed to their support for a period of three years even if the grant and contract support are terminated. From time to time the individual may also play some role in the instructional process.

Some departments have benefited significantly from the large umbrella grant under which a number of investigators can be supported. In industry and in national laboratories, the question of support for individual investigators does not arise explicitly because the individual is supported as part of larger ongoing programs for which the institutional management assumes responsibility. But the problem is serious in universities. Here the competition for scarce funds has intensified and exists in acute form in the case of the young unestablished investigator. Umbrella grants and contracts supporting the activities of a number of faculty members have very substantial advantages, especially for young physicists. Instead of each faculty member spending a significant fraction of the time writing proposals and progress reports to different agencies, one principal investigator takes care of such matters. Under the umbrella the young faculty members, for example, have access to excellent facilities, either on campus or as members of user groups at national laboratories. They spend little or none of their time worrying about funding to support either themselves or their activities. Thus, during the most creative period of their careers, they can devote themselves single-mindedly to their research activities.

The umbrella grant is also a mechanism that departments can use to develop specialties within the field. Increasing research specialization is

a striking tendency observed in site visits. During the 1960s there was a tendency toward comprehensiveness—hiring one or more physicists in each of the subfields of contemporary physics. This is no longer the case in a number of departments that see greater specialization as the way to achieve the visibility required to obtain research support.

Conclusions

Substantive vigor and excitement now characterize the university research effort in physics. However, other indicators suggest that several forces are combining to constrain the physics research environment in universities. Federal funding for university physics has declined in current dollars; graduate student enrollment has fallen rapidly since 1968, and PhD production has declined as well; the expense of research facilities has resulted in a greater concentration of resources in a smaller number of facilities, thus requiring many physicists to spend increasing amounts of time away from their home campuses; and the general decline in funds has resulted in cuts in supporting resources for research. Departments have little or no opportunity for expansion, and they are even having difficulty maintaining their existing size—all of which poses the prospect of a diminished flow of bright, young researchers into the discipline. The more highly ranked departments have been able to attract slightly greater proportions of students and larger amounts of funds in the shrinking research environment, but all departments have been affected in some degree by recent adverse trends.

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16. Ibid., pp. 24-25.
17. *Nuclear Science*, op. cit., p. 103.
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C. MATHEMATICS

The postwar development of mathematics in the United States has no parallel in the history of the discipline. In a period of 30 years, the mathematics research community in this country has grown from modest size and stature to the largest and strongest national mathematics group in the world. This dramatic growth has been propelled by three major forces: the injection of substantial amounts of federal funding into basic scientific research, significantly increased university enrollments, and the greatly expanded use of mathematics in various branches of science, engineering, and the social sciences. Remarkable advances in the discipline and its applications have accompanied the growth.

A review of some exemplary achievements in mathematics gives some flavor of the impact mathematics research has had on the other sciences and on society as a whole. In 1930, the late Norbert Wiener published, in the journal *Acta Mathematica*, a paper entitled "Generalized Harmonic Analysis," which has since become famous. Writing at an abstract level, Wiener exposed some general principles and new ways of viewing a branch of mathematics called "harmonic analysis." This abstraction made it appear to some that harmonic analysis had moved very far away from its origins in science—the study of the heat equation—to the analysis of harmonics as in music. But Wiener's work would later have profound effects on such diverse fields as communications engineering and oil exploration.

In World War II, Norbert Wiener, like many other mathematicians and scientists, turned his attention to the war effort. In February 1942, he wrote a restricted document (since declassified) entitled "The Extrapolation, Interpolation, and Smoothing of Stationary Time Series." In simple terms, it dealt with the problem of predicting the future value of a variable quantity based on an imperfect knowledge of its values at past times. It utilized ideas from his generalized harmonic analysis and introduced several new ones that were aimed at handling the various kinds of noise that obscure the true values of various quantities.

After some simplifications by others, his work was applied to meteorology, geophysics, and other fields, bearing enormous practical consequences. The applications to geophysics were worked on during the 1950s by applied mathematicians. The subsequent techniques so improved the ability to interpret and process seismic signals that vast new oil discoveries were made, creating billion-dollar-a-year industries. Wiener's impact on communications engineering can best be described by quoting from William L. Root's article "Contributions of Norbert Wiener to Communication Theory" in the 1966 issue of the *Bulletin of the American Mathematical Society*, dedicated to Wiener's memory. In speaking of Wiener's wartime paper on stationary time series, which appeared in book form in 1959, Root said:

> It was written primarily for electrical engineers, even though most electrical engineers of the 1940s could not read it. This was perhaps not a bad thing; the results were sufficiently interesting to provide a stimulus to engineers to acquaint themselves with enough mathematics so that they could read it. In 1965 most theoretical communications and control engineers can read it, and in fact are fairly conversant with its contents. There is now probably not a graduate program in control and communications engineering in the country in which the material of this book is not offered.

And so, 40 years later, the full impact of Wiener's achievement is felt.

Another way to appreciate the substantial impact of mathematics on science and engineering in recent years is to note the changes that have occurred in the mathematical preparation of students entering other fields. The economist of 30 years ago would probably have scoffed had someone told him that by 1977 every serious undergraduate student in his discipline would be expected to study calculus, linear algebra, and introductory mathematical analysis. Most likely he would have been astounded to learn that vast numbers of research economists in 1977 would be making use of functional analysis and other areas of twentieth-century mathematics. Similarly, it is unlikely that the electrical engineer of the 1940s could have foreseen that by 1977 every serious student of his discipline would need courses in linear algebra, group theory, logic, and probability in addition to the traditional courses in calculus and differential equations.

Thirty years ago all except a few mathematicians would have been amazed to hear that in 1977 crucial management decisions in government and industry would be based in part on the theory of convex bodies in spaces of many more than three dimensions. Yet all of these events and many more have transpired. They reflect the greatly increased involvement that mathematics claims in the theoretical fabrics of many fundamental scientific disciplines. Mathematics research in this country has continued to thrive into the 1970s, but concern has emerged that its present vigor may be lost if the structures that support the research activity continue to erode.

Trends in Research Funding

One of the distinguishing characteristics of pure mathematics is that research in the discipline generally requires no substantial dependence on equipment and instrumentation. (This may be changing, however. The computer does play a role in experiments in number theory as well as in group theory. There is evidence that it will also be increasingly used in statistics and, most importantly, in theorem proving—for example, the recent proof of the "4 color problem.") Applied mathematics

and computer sciences rely to a much greater extent on computer hardware, while pure mathematics researchers generally rely on their own ingenuity. Research funds in pure mathematics have generally been used to purchase research time by providing summer support for graduate students and by funding visiting professors, colloquia, and travel to broaden the channels of communication among mathematicians.

Trends in federal obligations for mathematics by agency for fiscal years 1971 to 1975 are shown in Table 1. Federal support for mathematics R&D in universities and colleges totaled $41.4 million in 1971, an amount that increased to $61.5 million in 1975. While this was a 48 percent increase in current dollars, constant dollar support actually increased 12 percent. The National Science Foundation is the principal funder of mathematics research, and it has become practically the only major source of pure mathematics funding. In 1971, NSF provided 40 percent of all federal funds for mathematics; this rose to 45 percent by 1975. Though DOD funding has increased somewhat in absolute amounts, its share of the total federal funds for mathematics has decreased. ERDA support for mathematicians has declined in absolute amounts over the period. Mathematicians argue that the spirit of the Mansfield Amendment has reduced mission-agency funding of pure mathematics research.

Although federal funding for mathematics research in universities has been increasing, the amount of federal support for graduate students in mathematics has sharply declined. Federal obligations for fellowships, traineeships, and training grants to universities and colleges have dramatically decreased from nearly $9.3 million in fiscal 1971 to less than $2.4 million in fiscal 1975.[1] Reductions in funding, the generally tightened academic job market, and perceptions of an oversupply of mathematicians have all led to reduced graduate student support. Many mathematicians believe that such policy changes have been too abrupt, have reduced support excessively, and constitute one of the main reasons that fewer young people are entering research careers.

As in chemistry and physics, competition among researchers for available support has intensified. The National Science Board estimates that basic research expenditures in mathematics in constant 1967 dollars per scientist and engineer in doctorate-granting institutions declined from a peak of $4,900 in 1968 to $3,800 in 1974.[2] Proposals to NSF tripled between 1967 and 1973, but the success ratio dropped from approximately 75 percent in 1968 to less than 50 percent in 1973. Moreover, the average grant size has declined from more than $33,000 in 1967 to just over $19,000 in 1973.

Although such figures are not strictly comparable because of a larger number of multi-year awards in the late 1960s, the trend nevertheless suggests that grants are being increasingly "squeezed" in light of limited budgets. The number of research assistants funded has dropped

Table 1

Federal R&D Obligations for Mathematics to Universities and Colleges by Agency, FY 1971-1975
(dollars in thousands)

Year	Total	NSF	DOD	NASA	ERDA	HEW	DOT	Other
1971	41,422	16,562	11,663	777	2,931	8,785	–	704
1972	50,712	22,268	13,402	552	2,809	8,947	1,568	1,166
1973	45,904	21,719	11,256	665	2,656	8,435	373	800
1974	51,931	23,729	12,347	1,003	2,254	10,838	565	1,195
1975	61,514	27,935	14,997	1,912	2,672	12,529	399	1,070

Source: National Science Foundation. *Federal Support to Universities and Colleges, and Selected Nonprofit Institutions*, Annual Publications, FY 1971-1975. (1975 publication in press.)

sharply, and a higher proportion of proposals rated "excellent" or "very good" by reviewers were not funded in 1973, when compared with 1971. Finally, another consequence of budget declines has been a decrease in the number of multi-year awards, although the number has increased slightly in recent years.[3] These indicators suggest a tighter funding environment than that of the mid-1960s; federal support for mathematics research, however, continues to show modest growth in current dollars.

The typical NSF grant in mathematics has virtually ceased to support any of the costs associated with conducting mathematical research beyond those of investigators' salaries for the summer months when they are engaged in full-time research. The typical grant provides only small amounts for secretarial support, publication costs, travel, and materials. More importantly, most grants have practically no funds for three vital elements in the research enterprise: graduate research assistants, young postdoctoral mathematicians, and research associates who work with the principal investigators. The result is that many such research costs have had to be transferred to the universities.

Effects of Declining Federal Support

Given the limitations of available data, funding trends by departments are as difficult to establish in mathematics as in other areas. Expenditure data are collected, for mathematics as for other fields, with the university—rather than the individual department—as the reporting unit. Moreover, different subfields of mathematics are likely to be organized differently in various universities. In some universities, pure mathematics is set off in a separate department; in others, applied mathematics and/or computer sciences are joined with pure mathematics to form a large mathematics department. The organizational

factor necessitates special caution in interpreting the data; yet the assumption that a substantial share of reported mathematics R&D funds is in fact spent by departments of mathematics still permits cautious inferences about funding trends.

Table 2 displays the average amount of federally funded mathematics R&D expenditures in 90 universities by Roose-Andersen mathematics department ratings for fiscal years 1972-75. The average amount of such funds expended by each of four institutions with highest rated mathematics departments (4.5-5.0) was $693,000 in 1972, rising to $894,000 in 1975, an increase of 29 percent. Between 1972 and 1975, 51 institutions with mathematics departments ranked below 2.5 on the Roose-Andersen scale each increased their federally funded mathematics R&D expenditures by an average of 86 percent over the period, and other categories of universities with departments of different quality rankings also experienced increases.

Table 2
Federally Funded R&D Mathematics Expenditures in Universities by Roose-Andersen Department Rating, FY 1972-1975
Average per Institution in Each Quality Category (dollars in thousands)

Roose-Andersen Rating	Fiscal Year				% Change
	1972	1973	1974	1975	'72-'75
4.5-5.0 (4 institutions)	$693	$877	$817	$894	29.0%
4.0-4.4 (4 institutions)	2,112	2,081	2,034	2,133	1.0
3.5-3.9 (9 institutions)	750	768	804	874	16.5
3.0-3.4 (7 institutions)	372	436	398	404	8.6
2.5-2.9 (15 institutions)	561	479	537	626	11.6
Below 2.5 (51 institutions)	124	169	210	231	86.3

Source: Derived from NSF Survey Data on Federally Funded R&D Expenditures in Universities. See footnote 2, page 86.

Since institutions with lower ranked departments begin from a lower base, smaller absolute increases produce higher rates of increase when compared with higher ranked departments. The average absolute increase in mathematics expenditures in each of the highest ranked institutions ($201,000) was almost double the average absolute increase in such expenditures in each of the lowest ranked institutions ($107,000).

Another set of somewhat more restricted departmental data portrays similar funding trends. Table 3 displays data on NSF mathematical sci-

ences support to different Roose-Andersen categories of departments for selected fiscal years. Two significant trends can be observed: The top-rated or distinguished departments increased their proportion of NSF support over the period as did the unrated departments; the strong departments (Category II) experienced a reduction in support.

Table 3
NSF Mathematical Sciences Obligations to Departments by Roose-Andersen Rating, Selected Fiscal Years (dollars in millions)

	FY 1967	FY 1970	FY 1973
Category I (4.0-5.0)	$3.51 (27.3%)	$3.72 (28.8%)	$4.65 (33.0%)
Category II (3.0-3.9)	$4.73 (36.7%)	$3.50 (27.1%)	$3.72 (26.3%)
Category III (2.5-2.9)	$1.85 (14.3%)	$2.13 (16.5%)	$1.90 (13.5%)
Category IV (2.0-2.4)	$1.10 (8.5%)	$1.32 (10.2%)	$1.17 (8.3%)
Unrated	$1.68 (13.1%)	$2.25 (17.4%)	$2.66 (18.9%)
TOTAL	$12.87	$12.92	$14.10

Source: National Science Foundation.
Note: The totals for NSF mathematical sciences obligations differ from the NSF total reported in Table 1 because a more narrow definition of "mathematical sciences" is used here.

While the trend in funding for the distinguished departments supports the view that the very best departments tend to improve their relative positions in a tightened funding environment, trends in the strong and unrated categories suggest that the thesis does not entirely hold across all categories. Two possible explanations may account for this: First, unranked departments may have specialized research interests or they may have assumed an orientation toward applied research where funding is somewhat more accessible. A second explanation may be that the tight academic job market has enabled unranked departments to upgrade their research programs by hiring high quality young investigators. Unfortunately, the amount and quality of available data do not allow systematic analysis of either explanation.

Trends in Graduate Student Enrollment

Although federal funding for mathematics has been increasing in current dollars, the number of graduate students in the discipline has declined. Annual production of mathematics PhDs is down from a peak of 1,281 in 1972 to 1,149 in 1975.[4] Total full-time enrollment in 120

matched doctorate-granting mathematics departments has also decreased from 8,958 in 1968 to 6,210 in 1975 (see Table 4). However, the distinguished mathematics departments have increased their proportionate share of graduate students. In 1968, they enrolled 13.6 percent of the total, a proportion that dipped to 12.9 percent in 1970 but rose to 15.9 in 1975. The distinguished departments have been the only category showing a consistent pattern of proportionate growth since 1972; departments ranked in the good (2.0-2.9) and adequate plus ranges registered the sharpest proportionate drop in graduate students, while the other categories remained relatively stable.

Changing graduate student support patterns have contributed to declining student numbers. Between 1969 and 1975, the number of students supported by fellowships or traineeships declined precipitously from 2,364 to 656. Until about five years ago, there were approximately 250 new NSF fellowships in the mathematical sciences each year; that number is now about 60.[5] Currently, about half of these fall in computer science and applied mathematics, and the other half in pure mathematics. The total number of students on fellowships or traineeships declined from 2,364 to 656 from 1969 to 1975. Within this environment, the distinguished departments have increased their proportionate share of graduate students with fellowships or traineeship support: In 1969, they enrolled 21 percent of these students; this proportion rose to 37 percent by 1975 (the absolute number declined from 479 to 243). A similar pattern exists in research assistantship support for graduate students. The total number of research assistantships in the same 120 matched mathematics departments declined sharply from 596 in 1968 to 272 in 1975; again, the distinguished departments increased their proportionate share from 27 percent (or 163 out of 596) in 1968 to almost 41 percent (or 111 out of 272) in 1975.[6]

Some mathematicians see a concurrent decline in the quality of graduate students, particularly at lower ranked departments. At the same time, new PhDs face an academic job market in which the available number of tenured positions has sharply declined. Temporary appointments are somewhat easier to obtain, but second or "permanent" positions, in the pure mathematics area at least, are not available in large numbers. One result of the research expansion during the 1960s is that many mathematics departments tend to have a large number of relatively young tenured faculty members. Over 50 percent of the 10,000 mathematical scientists employed in four-year colleges and universities in 1973 were between the ages of 30 and 39.[7] An NSF survey of 124 doctorate-level mathematics departments reported an average tenure ratio of 67 percent in 1974. This ratio is somewhat lower in private institutions (64.5 percent) than in public institutions (67.8 percent). Moreover, the survey reported that the tenure ratio in the "distinguished" or "strong" departments was higher than the average (70.9 percent).[8]

Table 4

Total Full-Time Graduate Enrollment in 120 Doctorate-Granting Mathematics Departments, by Quality Category, FY 1968-1975*

Roose-Andersen Rating	Enrollment, by Fiscal Year							
	1968	1969	1970	1971	1972	1973	1974	1975
4.0-5.0 (8)[a]	1,219 13.6%	1,161 13.0%	1,096 12.9%	1,131 13.4%	1,043 13.4%	1,070 14.8%	1,020 15.3%	987 15.9%
3.0-3.9 (16)	1,886 21.1%	1,976 22.1%	1,845 21.7%	1,732 20.5%	1,579 20.3%	1,507 20.8%	1,484 22.3%	1,360 21.9%
2.0-2.9 (38)	3,229 36.0%	3,108 34.7%	3,142 36.9%	2,989 35.4%	2,816 36.2%	2,489 34.4%	2,102 31.5%	1,960 31.6%
0.0-1.9 (31)	1,553 17.3%	1,509 16.9%	1,413 16.6%	1,514 17.9%	1,260 16.2%	1,121 15.5%	1,164 17.5%	1,049 16.9%
Not rated (27)	1,071 12.0%	1,178 13.2%	997 11.7%	1,071 12.7%	1,072 13.8%	1,051 14.5%	894 13.4%	854 13.8%
Total	8,958	8,932	8,493	8,437	7,770	7,238	6,664	6,210

*The percentages in each of the cells indicate the proportion of students enrolled in that quality grouping that year.

[a] The number in parentheses indicates the number of departments within the quality category.

Source: David W. Breneman, *Graduate School Adjustments to the "New Depression" in Higher Education* (Washington, D.C.: National Board on Graduate Education, 1975), Table 4, p. 22 and David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).

Mathematics departments, in short, tend to have relatively large numbers of young faculty and relatively high tenure ratios; most departments are in a steady-state environment of stable overall size in which the proportion of young faculty members will henceforth decrease. An American Council on Education survey of 53 mathematics departments showed that in 1968 the proportion of young faculty (defined as being within seven years of the doctorate) in the departments was 51.5 percent; by 1975 this proportion had dropped to 30 percent and was projected to decline to less than 27 percent by 1980.[9]

Summary of Site Visits

As in other academic disciplines, mathematics departments are characterized by heterogeneity in faculty size, tradition, perceived quality, and number of full-time graduate students. Departments in public institutions are more likely to have large service course enrollments that in turn require large numbers of teaching assistants. As noted earlier, the subfields of mathematics are likely to be organized differently in various institutions. Recent trends in federal funding have had varied effects on mathematics departments. The following summarizes recent developments as observed in site visits to 22 departments.

Category A (five departments visited). Ranked "distinguished" on the Roose-Andersen scale, these departments appear to be adjusting to the steady-state environment with varied success. Two appear to have no substantial problems, but the others expressed concern about high tenure ratios, budget stringencies within the university, higher teaching loads, and declining graduate student support. Yet views vary, even on these matters. One department chairman declared that "things are in pretty good shape." The tenure ratio poses no real problem. The lower number of graduate students is seen as a good development because faculty can devote greater attention to each student. The department continues to get the "cream of the crop," and since a certain critical mass of students is being maintained, the slightly smaller number of students poses no threat. Moreover, most faculty members enjoy some form of outside support. The one real change is that students graduating from this department are encountering greater difficulty in finding initial teaching jobs, especially those with any prospect for advancement. Furthermore, these students have an even more difficult time getting a second appointment—one which would find them closer to the tenure decision. The chairman concluded that "the department would have a little more freedom if we had a little more money," but all indicators pointed to continued excellence in research efforts.

The second department reported that federal funding cuts have hit graduate student support hard, and consequently the number of grad-

uate students has declined. The department has lost several junior positions, but the tenure ratio continues to be relatively low. The number of senior positions is "pretty much frozen," but the university has always been "tough" on tenure positions, so this is nothing new. The quality of assistant professors and graduate students continues to be high, and placing graduates has not generally been a problem. Confident of the continued excellence of his department, the chairman cites rising indirect cost rates and the drop in federal graduate student support (which has been partly offset by increased university support) as the only problem areas.

In the third department visited, every faculty member has outside research support. Placements have been good for graduate students, the quality of faculty is superb, and morale is generally good. However, some faculty members believe that students are gradually moving into more applied mathematical areas, and attrition is now greater among students after the qualifying examinations. Problems have begun to appear, however, of which "constant contraction and attrition" is the most serious. Because of the increasingly stringent economic base of the university, the size of the faculty, student support, and visiting professorships have all been cut and "money for computer time is getting short." These mathematicians are not worried about their ability to get summer support and other modest research support needs. They are worried mainly about the university "sinking under them," and about the diminished personal flexibility that results partly from tighter university management and partly from changes in federal granting policies. "Overmanagement, the cutting down of funds combined with the university contraction—these are our real problems."

Another department in this top category has experienced some unique problems, such as the loss of some particularly outstanding people. The department has 4 assistant professors out of 61 tenured appointments, which indicates some danger of an aging or tenuring-in problem. There has also been a decline here in graduate student fellowship support. Perhaps the most serious long-term problem is the prospect of greatly increased undergraduate teaching loads. The department's quality and its research output have not declined measurably, but pressures toward heavier teaching loads combined with the absence of new appointments and reduced student financial aids contribute to a trend that will make future research efforts somewhat more difficult.

The fifth department has begun to experience real difficulties. It has not made a tenure appointment since 1971, and there are no open tenure lines. Given this situation, younger faculty members are generally on term appointments with little hope of getting tenure. Federal support in the department as well as other outside sources of support have decreased. It is still possible to get summer support from NSF, but such support is no longer assured; for the first time, people in the department are not getting funded. The number of outstanding graduate stu-

dent applicants has declined, and fewer graduating PhDs can now find first-rate jobs; many are turning to junior college teaching positions. The quality and morale of graduate students appear to be in decline, and attrition among graduate students is higher. Moreover, to justify course offerings a larger number of students is now required. Though highly rated in 1969, this department has not been immune to erosion of its research environment.

Category B (four departments). Serious problems have begun to affect the research environments of these departments, ranked strong (3.0-3.9) in the Roose-Andersen ratings. In one department, research support has declined and a number of researchers are now without external support. Some faculty members no longer seek federal support, others submit proposals that go unfunded, and still others are too discouraged to seek research support from any source. The number of faculty members has been cut over the last several years—through attrition and a decline in the number of junior staff members. Because of the age distribution in this department, few retirements are expected over the next decade. By the department's own decision, the number of graduate students has been lowered because of poor job market prospects. Moreover, budget cuts have resulted in larger class sizes.

Faculty size in a second department also has been shrinking, in part because its unfilled senior positions have been rescinded. Moreover, graduate teaching activity has definitely declined, and the department is considering placing greater emphasis on their master's program. The number of graduate students is down by more than 50 percent, accounted for in part by the reduction in graduate student support. Air Force and Army support curtailments have been most striking, and NSF is now the principal source of external support. Finally, increasing bureaucratization within the university may be eroding the department's flexibility.

The third department has encountered similar problems. While most of the faculty is supported in some way (primarily summer support), some investigators have had their grants cut off. Fortunately, most young faculty members still have support, and the quality of assistant professors in the department is very high. According to the chairman, "The talent is so good that it is disheartening not to be able to promote people." The department is facing two principal problems: (1) a decline in the number of graduate students—and, perhaps more significantly, the decline in serious PhD applicants; and (2) a 15 percent reduction in faculty size. Both released time and summer support opportunities have diminished. At the same time, undergraduate enrollments are increasing. The picture that emerges is one of cutbacks in support money and in the size of faculty, a decrease in the number of serious graduate students, and an increase in undergraduate enrollments. These indicators suggest that the department is confronting a pinched research environment combined with larger undergraduate teaching demands.

The chairman of the fourth department declared that "we're better than we were a decade ago." More than half the department has external funding. The tenure ratio is such that excellent young assistant professors will still be promoted, but the standards for promotion here as elsewhere have been raised substantially. Some indicators suggest difficulties ahead. The number of graduate students has declined along with the reduction of federal graduate student support. Moreover, there is an extremely high attrition rate among graduate students. Undergraduate enrollments have increased and class size on the undergraduate level has gone up sharply. The chairman also worries that the trend toward applied research will hurt the department since his colleagues do not see themselves as applied mathematicians. In addition, increased bureaucratization is a matter of concern: According to the chairman, "In the past, it took only 3 pages to fill a promotion dossier and now it takes 50 pages to fill the same dossier.... The increased legalism is deplorable—it saps my energy." Higher undergraduate teaching loads, declining opportunities for young investigators, the drop in serious graduate students, and a perceived move to applied mathematics are the major problems this department faces.

Category C (eight departments). Most of these departments—ranked in the 2.0-2.9 or good and adequate-plus Roose-Andersen range—share the same types of problems. Funding has been more difficult to obtain, the number and quality of graduate students are in decline, and larger undergraduate course enrollments demand more teaching time.

One department has experienced a slight tapering off of federal funds. Five years ago, 80 percent of the faculty was funded; now only 60 percent has funding. This drop has not significantly affected the department's research program, since the money was never really large, accounting for only a portion of salary support and some travel as well as funding programs for visiting scholars. Though these are important, the research effort will go on in their absence. However, the department faces a very serious problem in attracting quality graduate students. The number of graduate students has dropped by one third, and their quality has declined as well. A sharp drop in applications suggests the possibility of a further decrease. The perception of a tight job market, the lack of federal support, and the fact that the university's teaching assistantships are not very competitive all help account for the decline in graduate students.

This decline hurts in several ways. First, there are simply fewer people around to teach undergraduates (the number of teaching assistants has declined by 40 percent). Just as importantly, there is now a smaller audience for the necessary advanced courses in mathematics. The increased emphasis on applied mathematics, statistics, and computer science contributes significantly to pressures for a more applied orientation in PhD placement. In a somewhat related issue, the department is

experiencing increasing contact with the students in applied mathematics, statistics, computer science, and the social sciences. This development will certainly increase "service" demands, which could adversely affect the research efforts of the department if no new positions are made available. In sum, the declining number of high quality graduate students and the prospect of increased teaching assignments appear to be greater threats to this department's research environment than a decrease in federal funding.

A second department has been adjusting to the termination of its Science Development Grant, which has meant that only about one third of the faculty members now receive external funding. Less than half the department is tenured, and the high termination rate of assistant professors is likely to keep this ratio low. However, both the quality and number of graduate students have declined; the number of teaching assistants has consequently dropped. The graduate program is clearly less active now than it was five years ago. The chairman cited an "accumulation of a lot of things creeping up" to impinge on the vitality of the department: increasing teaching loads, larger class sizes, and greater administrative demands.

In another department, faculty size has increased but is still viewed as inadequate in light of undergraduate enrollment demands. The tenure ratio is 86 percent. The number of NSF summer research support grants has risen from 3 to 13 over the last eight years. Forty percent of the faculty are now funded, with most of the funds generated by younger faculty in the form of summer support. Nonetheless, the days of adequate support have passed, and the chairman characterized the current budget as austere. In general, faculty receive less released time than they used to, and summer teaching loads have increased. Compensation for journal page charges are more difficult to obtain. The department has approximately 30 graduate students and is considering a master's program of professional training in applied mathematics.

The indicators in another department all point to a shrinking research environment. The number of faculty positions is down, despite large undergraduate enrollments. Graduate student and teaching assistant numbers have decreased, and the number of graduate courses has dropped by 40 percent. Many students now stop at the master's level, and more students are shifting their interests to applied mathematics. Finally, travel money is needed to insure the interaction necessary in mathematics research. The chairman of another department in this category declared that, since basic mathematics research is no longer supported by DOD, he has switched his interests to applied research. However, some of his colleagues have not changed their interests and consequently no longer receive external support. In another department, the number and quality of graduate students have decreased as the job market has tightened. The number of students in the

graduate program is now only one third of the earlier peak level.

Category D (five departments). The departments in this category are not rated by Roose-Andersen. One of the characteristics of the group is a greater likelihood of moving into applied research programs. While no single pattern characterizes these departments, the experiences of two departments give the flavor of the varied conditions prevailing in the departments visited in this category. The first department has less than half the amount of sponsored research it had in the late 1960s, in part because of the drop in DOD funding. The tenure ratio is 75 percent, but in this case a balanced age distribution helps to offset a tenuring-in problem. The number of graduate students has dropped; and, while the master's program has been consistently strong, the doctoral program appears to be decreasing in strength. This decline in graduate students means that fewer advanced courses will be taught, leading the department to consider seminars for the young faculty to sustain the vitality of their research efforts. Finally, it appears inevitable that teaching loads will be increased.

The other department in this category has obviously shifted to applied mathematics, partly, but not entirely, because NSF support for pure mathematics has dried up. The department has set up joint programs with engineering, medicine, and computer sciences, and the support pattern reflects this shift. Professors in the department have two research grants from NIH (one of which is for the development of differential equations relevant to nerve transmission), two from the Air Force, and one from the Naval Research Lab. The shift to applied research is largely a response to job prospects, and both faculty and students are comfortable with this development. The number of teaching assistants has been cut by 20 percent, but the quality of graduate students (40 percent of whom are foreign) is reportedly up. Faculty have engaged in an active recruitment effort. This department has shown great flexibility in shifting to a heavily applied mode of research and teaching.

Conclusions

Although the highest ranked departments generally have been the most successful in maintaining or improving their research environments, general indicators suggest that the environment for mathematics research will become more difficult over the next decade for the entire spectrum. Funding is harder to obtain. Undergraduate teaching loads have been increasing significantly. More important, perhaps, the flow of new research talent into the discipline appears to have become limited. The number of graduate students is down sharply; academic job opportunities for young mathematicians have been severely re-

duced. While the quality of American mathematics research continues to be high, serious erosion may occur over the next decade.

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1. *Federal Support to Universities and Colleges, and Selected Nonprofit Institutions* (Washington, D.C.: National Science Foundation), Annual Publications. (1975 data in press.)

2. National Science Board, *Science Indicators—1974: Report of the National Science Board, 1975* (Washington, D.C.: National Science Foundation, 1975), Table 3-13, p. 199.

3. Source: National Science Foundation. Internal memorandum.

4. National Research Council, Commission on Human Resources, *Summary Report 1975: Doctorate Recipients From United States Universities* (Washington, D.C.: National Academy of Sciences, 1976), Table 1, p. 12. 1972 data from *Summary Report* of that year.

5. These figures on NSF fellowships in the mathematical sciences are estimates.

6. David W. Breneman, "Effects of Recent Trends in Graduate Education on University Research Capability in Physics, Chemistry, and Mathematics," *The State of Academic Science*, Vol. II (New Rochelle, N.Y.: Change Magazine Press, 1977).

7. *Characteristics of Doctoral Scientists and Engineers in the U.S., 1973*, NSF-312A (Washington, D.C.: National Science Foundation, 1974), Table B-5, p. 30.

8. *Young and Senior Science and Engineering Faculty, 1974: Support, Research Participation and Tenure*, NSF 75-302 (Washington, D.C.: National Science Foundation, 1975), Tables B-8, B-9, B-10, B-11, pp. 24-25.

9. Frank J. Atelsek and Irene L. Gomberg, *Young Doctorate Faculty in Selected Science and Engineering Departments, 1975-1980*, Higher Education Panel Reports, No. 30 (Washington, D.C.: American Council on Education, 1976), Table 3, p. 14.

D. LIFE SCIENCES

This section reviews recent developments in the life sciences primarily from the perspective of molecular and cellular biology. There have been some significant advances in organismal and evolutionary biology, in the agricultural sciences, and changes in the support policies related to such areas, but our primary focus here is on the biomedical and human disease-related areas of the life sciences. (We will use the terms "biology" and "life sciences" interchangeably in this context.)

Since the early 1950s, a revolution has occurred in biology. It was sparked by the discovery in 1953 of the structure of DNA, the fundamental molecular matter of the gene, which signaled the beginning of an era in molecular biology. This eventually led to a boom in biological research with consequences that may equal those of Darwin.

The revolution inspired by the double helix[1] was of such magnitude that it overshadowed a development of almost equal consequence: the exploration of the nature of proteins. Before the full force of molecular genetics was felt, the detailed architecture of several proteins was described, and the connections between DNA structure and the proteins that actually regulate life processes were firmly established. These related events drew physicists, chemists, geologists, and astronomers toward biology. All were bound by the almost unimaginable notion that a scientific description of the origin of life was within the realm of the attainable.

After the discovery of DNA, the first important stage in the development of molecular biology was the exploration of bacteria and viruses; to some extent this continues today. However, molecular biology, which has given the contemporary biologist many of his methods and tools, is gradually approaching a second phase—one in which its techniques and concepts are increasingly incorporated into cellular biology. Molecular and cellular biology have thus been transformed for the study of organisms more complex than bacteria—including man.

In this focus on eucaryotic biology fundamental questions are being asked that relate to all organisms exhibiting differentiation or specialization, i.e., having different kinds of cells or tissues. The major areas of study involved are: development—from a cell to an organism—and differentiation—how cells become specialized for certain uses early in an organism's life. Health agencies are naturally interested in these new fields of research and their relation to disease. Of course, there are no guarantees that the mystery of cancer would be solved, for example, by research on undifferentiated cells, but it is certainly a promising avenue. Another obvious application is testing, through observation of the effects on differentiation, whether or not a chemical or environmental agent is dangerous.

Still another biological research frontier relates to a special aspect of differentiation: how cells cluster and organize with those of the same

type. Many biologists presume that the secret of the clustering mechanism lies in the membrane because two cells generally come in contact with each other by their surfaces. This is another area of great potential benefit for improved health care. Take, for example, the fact that any vertebrate system recognizes that the organs, tissues, cells, and even molecules of any other vertebrate are not its own. This has important ramifications beyond the obvious example of the use of antisera in the control of infectious diseases and the body's rejection of organ transplants. Many children, for example, cannot secrete enough "growth hormone" from their pituitary glands to develop properly. This hormone can be purified from pituitary glands, making normal development possible. But since we lack sufficient human pituitaries to meet the demand, further progress depends on either synthesizing human hormones (which appears very unlikely in the near future) or improving our present knowledge of cell membranes and how to enhance their compatability with animal growth hormones.

Two other fields in biology are at the cutting edge of the discipline. The first involves the identification of cellular and subcellular structures. The second field, neurobiology, includes but transcends cellular biology. The last few years have witnessed a dramatically increased interest in neurobiological research, which is based on the presumption that even the most complex biological system can be understood in molecular and cellular terms. The mood in the fields is one of great excitement; no horizons seem too distant. Investigators in all the major biology departments we visited shared the feeling that the discipline is on the edge of major breakthroughs.[2]

Yet the life sciences are not without problems. One acute concern is that of the scientists' ethical responsibility to the wider public—most vividly illustrated by the case of recombinant DNA research. This research involves the insertion of genetic material into bacteria and the corresponding creation of new material. Thereafter the bacterial cell manufactures not only the regular complement of proteins necessary to live, but it will also synthesize and secrete new proteins. The potential benefits of such research are great. If the world needed a protein difficult and expensive to obtain, massive quantities of the bacteria could be "programmed" to manufacture the protein. Other benefits would accrue if we were then able to find ways to excise potentially dangerous pieces of DNA from sperm or egg cells (for example the gene causing sickle cell anemia).

The potential benefits are substantial but the possible dangers are far reaching. In general, it is not known what synthesizing potential the transformed organism might have. It could produce harmful agents. For example, most work done thus far has been on *Escherichia coli*, known as *E. coli*, a common bacterium in the large intestine. Generally noninfectious, it ordinarily does not secrete harmful toxins through the intestinal membrane or other products that can be absorbed.

E. coli bacteria are useful in the digestive process, but some fear that recombinant DNA research might produce a dangerous strain of *E. coli*, one that would synthesize harmful substances or cause widespread infection resistant to antibiotics. Some knowledgeable observers worry that the DNA inserted into the bacteria might lead to new proteins or toxic substances whose dangers are presently unknown.

Whatever the merits of the arguments, the issue has stirred wide-ranging controversy. For the future of science in general, the most significant fact is that the controversy has extended beyond the scientific community into the wider political arena. In Cambridge, Massachusetts, the city council passed a resolution in July 1976 calling upon Harvard and MIT to agree to a three-month moratorium on all recombinant DNA research.[3] Thus universities must now deal not only with federal and state policies, but even with regulations at the local level.

Trends in the Life Sciences

Given the scientific advances in the field, it is hardly surprising that the life sciences have witnessed dramatic growth within the past decade—in R&D funding, graduate enrollments, and their relative share of total federal funds for academic research.[4] Table 1 shows federal R&D obligations to universities and colleges in the life sciences by agency for fiscal years 1971-1975. Total federal funding of life sciences R&D in universities exceeded $1.2 billion in 1975, and HEW (primarily NIH) accounted for 80 percent of this total. The fact that medical schools play such a large part in the total funding pattern in life and biomedical sciences greatly complicates any effort to make distinctions among departments and subfields within the various disciplines.

In general, a pattern similar to that observed in physics, mathematics, and chemistry also exists with respect to the life sciences: Those departments perceived as distinguished according to the Roose-Andersen peer ratings tend to be well supported. Excellent biologists in less highly ranked institutions have also generally been well supported, although the organizational diversity of life science departments makes systematic assessment extraordinarily difficult.

Developments in Agricultural Research. Agricultural research in the U.S. had its origins in Lincoln's administration with the Morrill Act, which allocated a tract of land to each state for the site of an agricultural college. Subsequent enactments set up a funding base for these schools, in particular the Hatch Act of 1887. This system established a fixed amount of money for salaries and research that would be supplemented by state monies. Support for individual projects dwindled to a very small amount over the intervening years, leaving in many cases only a few thousand dollars per year for each investigator. In short, the

Table 1

Federal R&D Obligations to Universities and Colleges in the Life Sciences by Agency, FY 1971-1975 (dollars in thousands)

Year	Total	HEW	NSF	DOD	NASA	ERDA	USDA	EPA	Interior	Commerce	DOT	Other
1971	741,481	586,633	46,491	25,264	11,576	26,364	52,476	3,839	2,243	683	—	5,912
1972	896,376	710,541	54,487	24,409	6,624	24,848	61,129	4,707	1,853	1,877	370	5,531
1973	934,177	743,540	56,968	21,801	6,498	24,681	65,308	4,730	3,466	1,490	2,717	2,978
1974	1,128,236	931,900	59,203	19,353	6,036	27,756	65,362	5,623	3,733	1,686	38	7,546
1975	1,209,052	966,623	55,364	17,427	6,684	31,423	75,225	13,729	5,349	3,475	1,490	32,257

Source: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions*, Annual Publications, Fiscal Years 1971-1975 (1975 publication in press).

system evolved in such a way that the land-grant universities had research personnel but very little support money for equipment, supplies, and technicians.

In the late 1950s and early 1960s, NIH came to the assistance of many plant and animal researchers whose projects only indirectly related to human health-oriented research; photosynthesis, plant virus, and plant disease studies were supported by the Institute. But at the end of the 1960s, NIH reversed its policy, and many capable plant and animal scientists were left with little or no support. NSF picked up some of these individuals, but usually not at the level of earlier support. Others were left with only the small amounts supplied by their agriculture experiment stations.

The attention to food problems in the 1970s, and the growing U.S. exports of wheat, corn, and other grains partly due to droughts and crop failures elsewhere, focused new attention on the problems of the agricultural sciences. Two important studies, the Pound Report and the Wittwer Report, have addressed the problems of agricultural research in the U.S. Both identified the major weaknesses of the U.S. Department of Agriculture as: (1) the almost total lack of hiring of new or replacement personnel since 1966 in the USDA in-house and branch stations, (2) rigidities in management and research approaches resulting from an aging pool of manpower, and (3) the generally lower quality research investigator the USDA had attracted since the 1920s.[5] The Wittwer Report suggested a separate agriculture research-granting agency that would allow nonagriculture-oriented universities to compete for funding. Additional funding for the USDA, at a time of tighter employment for new PhDs, might also bring new energy to the in-house USDA laboratories and reverse the Department's declining reputation.

The agricultural field holds both great promise and unique difficulties that we cannot deal with here. Most of the challenges are related to food production, where both plant and animal researchers have an important role to play. Some of the most urgent scientific concerns related to plant biology include: (1) the basic biology N_2 fixation and how it can be controlled, the practices governing biological specificity, genetic manipulation, and the factors that may allow for increase of food production; (2) the ability of plants to withstand stress, i.e., drought, disease, heat, and cold; and (3) the development of new concepts and techniques for plant improvement.

Graduate Student Enrollment. Graduate enrollment has not been the severe problem for the life sciences that it has been for physics, mathematics, engineering, and to a lesser extent chemistry. While graduate student enrollments in the physical sciences declined between 1970 and 1974, the number of graduate students in the biological sciences increased by 22 percent.[6] Moreover, many areas of life sciences are

widely perceived as being closely related to health care, environmental quality, and other social goals. This is reflected in substantial funding as well as increased interest on the part of graduate students. Compared to many other fields, the life sciences appear at first glance to be unusually fortunate. Ample funding, high quality graduate students, a broad base of public support, and a climate of confidence—all of the ingredients for continued and dynamic progress seem to be present.

But a closer look into the life sciences reveals the beginnings of serious problems and suggests a much less sanguine outlook for the future. In part the strains that are beginning to affect the life sciences are similar to those already discussed in physics, mathematics, and chemistry, but there are also distinctive developments that merit attention. The forces affecting the life sciences still contain many favorable elements, and the problems discussed here need to be kept in perspective. Yet the overall situation requires concern and close attention by science administrators in the government and in the scientific community.

Instrumentation Needs. Supporting resources and instrumentation needs are becoming a serious worry to many investigators. Governmental funding policy has tended in recent years to stress salary support for investigators, technicians, and other research personnel, with less emphasis on facilities and equipment.[7] Within the life sciences are fields that have only recently become instrumented or are on the threshold of requiring more expensive facilities; thus equipment budget cuts have presented special problems. The chairman of a major biological science department expressed the matter in these terms: "We are in an instrumentation crisis. New developments make turnover very rapid and many institutions cannot keep instruments up-to-date. We are in a different position from physics or chemistry; physics was instrumented in the forties and fifties and chemistry in the fifties and sixties. Many areas within biology are just now becoming highly instrumented, but now the funds are tighter." As the research frontiers have rapidly expanded in molecular and cellular biology, the space needs for investigators have increased as well. Many departments, even some major ones, are facing the problem of old buildings requiring major renovation to be usable as modern biological science facilities.

Research Opportunities for Young Scientists. Just as in other fields, opportunities for young life scientists have been sharply curtailed, leading to the concern expressed by the President's Biomedical Research Panel that the country may face the danger of "skipping a generation" of biological scientists if current tendencies continue.[8] "Skipping" is perhaps most accurately defined as the loss to the field of some of the most gifted young scientists, who may be drawn into alternative careers.

Distinctive elements in the life sciences make present and future lines of development more difficult to predict than is the case with physics or

chemistry. The narrowing of opportunities for young biological scientists has occurred more recently than it did in the physical sciences, and for somewhat different reasons. The life sciences have more directly felt the impact of changes in government policy. The entire biomedical/life sciences system, which grew rapidly as a result of a heavy infusion of public funds, has in turn been adversely influenced by abrupt shifts in federal policy. Changes in government policies toward traineeships[9] and research career development awards, in particular, have had an abrupt impact on employment opportunities for research scientists in the life sciences. There have been few ready alternative sources of employment. Whereas in chemistry, for example, industry has traditionally served to some degree as a potential employer for young research chemists, there is a much weaker link between industrial research and university-trained life scientists. Only in the research-intensive pharmaceutical industry and in some industries concerned with pollution abatement have young research biologists found an open industrial alternative to university or university medical center employment.[10]

Of course, a variety of influences operate to affect institutional practices, but the dependence on government and the close link between university research and training functions and public policy is more direct in the case of the life sciences. Thus, the potential for very rapid change exists and in fact sharp changes have occurred in many biological science departments.

Implications of Rapid Changes in the Life Sciences Environment

From the period immediately following World War II until only very recently, there was an almost unlimited capacity to increase the size of life science departments without drawing on general university income. But the prospects for continued university growth have very suddenly and abruptly halted. In addition, university administrators have come to believe that the number of life science faculty must be directly correlated with the university's educational missions. The size of these departments has thus been questioned, and uncertainties suddenly confront life science departments for the first time in recent memory.

University Life Science Departments and the Medical Schools. The immediate reevaluation has focused on the preclinical (or basic science) departments in academic medical centers. It is not an exaggeration to speak of a "crisis" in the relationship of these departments to their sister departments in the arts and sciences divisions and to the clinical departments of the medical school. The size of the preclinical departments, their role in the teaching mission of the medical school and of the university at large, and their future as centers of research and train-

ing—all have come under serious question in nearly all major universities with large academic medical centers.

Recent developments in graduate training in biochemistry illustrate the point. Twenty years ago, it would have been accurate to say that biochemistry PhDs were usually trained in medical schools. Since then, as biochemistry has become the unifying discipline in the life sciences, the university arts and sciences schools have taken up the great share of graduate training in biochemistry. Students not seeking a career in medicine have often found it easier to take their graduate training in the regular biological science departments, resulting in a sharp drop in graduate enrollment in the medical schools' basic science programs.

Since biochemistry is no longer strictly a graduate discipline and medical students now customarily receive substantial training in biochemistry as undergraduates, the role of the medical school preclinical (or basic science) departments is increasingly being questioned. Medical schools simply do not know how to rationalize their large basic science departments. As these departments stopped expanding, and in some cases began to shrink, one avenue of employment closed to young research scientists. It is not entirely clear what pattern will prevail for the life scientists, who have fewer opportunities in industry or government than do their colleagues in physics, applied mathematics, chemistry, and engineering. One consequence observed in our site visits has been a tendency toward longer periods of postdoctoral training and sometimes second and even third stints as postdoctoral fellows.

The role of the medical centers' basic science departments is only one aspect of the relationship between medical schools and the rest of the university. As undergraduate enrollments in the premedical curriculum have swelled, strains have been placed on the life science departments. At some universities heavy teaching loads are borne by the arts and sciences biology departments, while medical school colleagues have very light teaching loads and ample resources for research. In the face of heavy teaching responsibilities, the young faculty member in an arts and sciences department may find it especially difficult to carve out a research career. Some departments have tacitly decided at an early stage that certain assistant professors will not be considered serious candidates for tenure and will therefore assume very substantial teaching burdens. Others will be protected and given an opportunity to pursue sufficient research and generate continued federal research support. Such practices create tensions within departments and pose serious management problems for the universities.

The relationships between medical schools and the universities are so varied, so complex, and so subject to local nuances that few generalizations can be made. It is evident, however, that the role of each in research and teaching has become an issue of great concern. Large numbers of faculty and administrators feel the need for a new analysis of

medical education that would establish some clear guidelines for action, similar to the comprehensive and authoritative Flexner Report of 60 years ago.[11] Institutional questions of this sort are not easily addressed within the framework of the project grant system; yet the continued vitality of the academic research effort, which is vital to the nation, will be strongly influenced by the resolution of these broader issues.

Complex Departmental Structures. The intricate organizational issues confronting life science departments are also a product of the dynamic state of the science itself. The extent of rapid change in departmental structure is striking; more than half of the life science departments we visited have undergone some form of reorganization within the past five years. It is always difficult to relate research frontiers of a rapidly changing field to formal department structures. But although the dynamic expansion of the research frontiers across traditional departmental boundaries is often a natural and desirable development, the accompanying overlap and blurring of disciplinary boundaries may lead to subsequent conflicts that can prove injurious to the further progress of research. As central university administrators seek to structure departments economically, deploying personnel primarily to serve instructional needs, conflicts arise between central administrations and departments and among different branches of the life sciences.

Organizational arrangements will also have a bearing on whether the life sciences can achieve links among its subfields. A critical issue in the minds of many life scientists is how to integrate all the areas that have splintered off from the classical single-field biology department. The complaint of a zoologist is characteristic: "Until three years ago, we had a genetics group in the department. They were good to have around. Then they split off and formed their own department. They took their grants and students with them and moved to a different building. We never see them any more, and we don't have anyone in genetics to talk to."

The patterns in arts and sciences divisions are quite diverse. The comprehensive biology department covering all subfields is rare but does still exist in some universities. The specialized department is more common, usually emphasizing molecular and cellular biology with little or no representation of evolutionary and organismal biology. Frequently, specialization has proven highly successful for receiving research support, given the current emphasis on biomedical research. Various interdisciplinary arrangements exist in different universities.

The recent history of a distinguished biology department at a private university illustrates the extent of organizational disarray. Four years ago, biochemistry and molecular biology split off and formed a separate department. This left two groups in the original biology department—evolutionary and population biology, and cellular and developmental

biology. The latter two groups then split and formed within the department two subgroups—cellular and developmental, and organismal and environmental. A complex pattern of interactions has emerged: The biochemists have close relations with the cellular and developmental group, yet the organismal and environmental group lacks any close community of interest with the cellular group despite their nominal affiliation within the same department. At another private university biochemistry has recently split off from the biology department to join the department of molecular biophysics. Members of that biology department who have expressed dissatisfaction with the arrangement because of the loss of regular contacts with biochemists are now trying to absorb molecular biophysics and biochemistry.

The typical organization at public universities, though somewhat distinctive, is similarly complex. At a major western public university, the Organization for Biological Studies cuts across many colleges. Botany, zoology, and genetics are all separate departments within arts and sciences. Microbiology, physiology, and anatomy are in the medical school. Finally, a biology component exists within oceanography as well as in the forestry and fisheries school.

At many of the biology departments visited uncertainty over the future status of the department and a vague apprehension was evident, even though departmental research efforts were generating substantial enthusiasm. Surprisingly, morale was depressed at many life science departments, although they appeared relatively well off in terms of research support and graduate student enrollments. Clearly, the division of departments into rival camps, or fights between related departments in various divisions of the university, contributed to the low morale of some of these life science departments.

Different universities have dealt with departmental divisions in the life sciences in different ways; none has expressed complete satisfaction with its arrangements. Some arts and sciences divisions apparently favor the large umbrella-type department, whereas in medical schools the tendency is to create a new department as soon as a new research field has been identified. There is probably no uniform organizational formula that universities either can or should pursue, but it seems certain that increasing thought will be devoted to such issues in the future.

Targeted Research. The life sciences reflect the areas of basic scientific inquiry where practical applications are most often readily apparent to the general public. This is in part a source of their great strength; the desire to improve the nation's health care doubtless explains why continuing high levels of federal research support have been available while other science fields have experienced declines. State legislatures, too, are typically more favorably disposed toward requests for research facilities when a health mission is involved.

But the identification of basic scientific activity with short-run applications has meant problems for the life sciences as well. To a larger degree than in many other scientific fields, the issue of balance in the support patterns across the major subfields of the life sciences has been an acute concern. Subfields not directly connected to normal and diseased states of organisms have had greater difficulties getting support. Further, the achievements of biomedical research have whetted the nation's appetite, resulting in even greater emphasis on specific applications in the nation's biomedical research effort. There is also a growing tendency to direct research support toward short-term objectives. The biomedical research community is concerned that this tendency may inhibit the flexibility and initiative of the individual investigator.[12]

Clearly, it is important that the contribution of biomedical research to the elimination of disease continue without interruption or diminution. Significant progress has been made in the past several decades toward improving health services. For example, there is a group of diseases of biochemical origin whose causes can be identified as the absence of particular enzymes. PKU is one such disease that now can be controlled; Tay-Sachs disease is another, for which the cure has not yet been found. Basic research in the life sciences has also resulted in large advances in the treatment of certain cancers. Hodgkin's disease and some childhood cancers are now more efficiently treated because of better diagnoses and advances in chemotherapy. The treatment of heart disease has also shown some advances in recent years, as the level of lipids in the blood has been identified as a contributing factor.[13] In the diagnosis of heart disease, part of the profile is now based on triglycerides and is done through thin-layer chromatography. A product of basic research in biochemistry in the 1950s, this illustrates the relatively short time lag between scientific inquiry and clinical applications.

Indeed, many significant medical diagnostic tools in use today are related to research performed within the past several decades. Electrophoresis, first discovered by Scandinavian scientists in the mid-thirties, became a widespread diagnostic technique for a number of diseases not long after World War II, when it was recognized that the process could be done very simply with a piece of filter paper dipped in liquids of positive and negative charges. When current is applied and the paper is dried, bands appear that represent proteins. This technique, called "paper electrophoresis," is now one of the most important diagnostic tools in medicine, and millions of these tests are performed every year in the United States for a matter of a few cents each. Similarly, experimental research after World War II, following up on the 1939 Russian discovery of "transamination" and the subsequent discovery that this reaction occurred in the liver, led to an important diagnostic technique for hepatitis.

The issue that has increasingly concerned scientists and science ad-

ministrators, however, is whether the apparent effort to push harder for practical applications has proceeded too far and upset the balance between investigator initiative and social need that has worked so effectively in the U.S. biomedical research effort. During our site visits we noted several adverse consequences of the apparent shift in government policy toward short-term goals. First, the imbalance in support patterns is more pronounced in the life sciences than in many other fields, and it could have serious long-term consequences. It is perhaps natural that the largest share of research funds in the life sciences should go to investigations related to the fundamental processes of normal and diseased states in organisms, since larger numbers of superbly trained scientists are working in these areas. But the funding agencies' neglect of classical biology fields is unhealthy for the long run. Perhaps more than in many other fields of science, there are gaps in the support patterns across the life sciences; some potentially important subfields are receiving inadequte attention.

Second, the emphasis on short-term goals could cause researchers to shift into areas of lower promise and to neglect the most creative scientific endeavors. Established investigators in general do not yet appear to have been markedly affected by the shift in public policy, so long as they have continued to work in their areas of proven accomplishment. But greater difficulty arises when an established investigator seeks to undertake research along novel lines, partly because the funding climate favors "safe" research. More serious, perhaps, is the impact on young scientific investigators. As a zoologist in a leading department formulated the problem: "The young faculty member is locked into what he did as a graduate student. He cannot afford to take risks. We probably would have rejected Charles Darwin for tenure because he hadn't published enough. The young guy often chooses a research subject that he knows is a safe bet, first, to be funded and, second, to be published." The chairman of a distinguished biology department agreed by noting that "junior faculty are under an unhealthy pressure to show short-term results."

Many factors, of course, contribute to the "play it safe" mood, not merely actual or imagined changes in funding strategies. The feeling that the inventiveness of the scientific effort could suffer was not unique to the life sciences; indeed, it was perhaps the most widespread fear noted in the site visits. But there was a greater urgency about the issue in the life sciences because the total scientific effort seemed to be more immediately influenced by public policy changes. Still, the issue must be kept in perspective. The undercurrent of apprehension has to be seen in the total context of great intellectual excitement along a number of research frontiers, a strong sense of purpose and commitment among scientists at all levels, and a general confidence that society will continue to seek out and support outstanding scientific research.

1. See James D. Watson, *The Double Helix* (New York: Atheneum, 1968).

2. As part of the work of the President's Biomedical Research Panel, biomedical and behavioral scientists evaluated the interrelationship between research in the field and the "health of the nation's people." For the reports of the 11 interdisciplinary clusters, see "The Place of Biomedical Science in Medicine and the State of the Science," *Report of the President's Biomedical Research Panel*, Appendix A, (OS) 76-500 (Washington, D.C.: Department of Health, Education, and Welfare).

3. Barbara J. Culliton, "Recombinant DNA: Cambridge City Council Votes Moratorium," *Science*, Vol. 193, No. 4250, July 23, 1976, pp. 300-301.

4. For detailed discussion, see Chapter II, "The Shift to Support of the Life Sciences," and Figure 7.

5. National Research Council, *Report of the Committee on Research Advisory to the U.S. Department of Agriculture*, PB-213338 (Washington, D.C.: National Academy of Sciences, National Research Council, 1972). *Enhancement of Food Production for the United States* (Washington, D.C.: National Academy of Sciences, 1975). See also Nicholas Wade, "Agriculture: Academy Group Suggests Major Shake-Up to President Ford," *Science*, Vol. 190, December 5, 1975, pp. 959-961.

6. American Council on Education, Division of Educational Statistics, *A Fact Book on Higher Education: Enrollment Data* (Washington, D.C.: American Council on Education, Second Issue, 1976), pp. 76. 118-119.

7. The proportion of NIH research grant funds allocated for laboratory equipment has declined from 11.7 percent in 1965 to 5.7 percent in 1974. Source: National Science Board, *Science Indicators—1974*, Tables 2-12, p. 181. For a fuller discussion of supporting research services, see Chapter V.

8. *Report of the President's Biomedical Research Panel*, op. cit., p. 32. See also Chapter V for a fuller examination of the issue.

9. For example, NIH obligations for fellowships and traineeships fluctuated from $23.7 million in 1971 down to $12.2 million in 1973 and up to $58 million in 1975. See *Basic Data Relating to the National Institutes of Health, 1976* (Washington, D.C.: National Institutes of Health, 1976), Table 7, p. 14.

10. NIH, forestry and fisheries agencies of federal and state governments, USDA, and a few other agencies also provide research opportunities for life scientists. But basically the employment opportunities for researchers are more heavily academic in the life sciences than in most other fields. For example, in 1973 the percentage of new doctorate recipients employed in academic jobs was 36 percent in chemistry and 39 percent in physics; in the biosciences, however, it was 66 percent. See Allan M. Cartter, *Ph.D.'s and the Academic Labor Market* (New York: McGraw-Hill, 1976), Table 10-1, p. 225.

11. A. Flexner, *Medical Education in the United States and Canada* (Boston: Updike, 1910).

12. The President's Biomedical Research Panel cited the "steady decline in the percentage of extramural funds of the NIH being spent for traditional research grants." The Panel expressed concern "about this trend away from this highly respected and enormously productive instrument of support." *Report of the President's Biomedical Research Panel*, op. cit., p. 17.

13. See "Tissue and Organ Biology Interdisciplinary Cluster" in "The Place of Biomedical Science in Medicine and the State of the Science," Appendix A, *Report of the President's Biomedical Research Panel*, op. cit.

E. ENGINEERING

Engineering has been described as "the bridge between science and society."[1] A strong and versatile national engineering effort is essential to apply the discoveries made in all fields of science to human needs. As highly trained problem solvers who draw upon knowledge in the basic sciences, engineers devise methods, designs, and products that can be applied to the solution of social and technological problems. When a problem cannot be solved with existing basic knowledge, engineers may do the fundamental research necessary to attain a practical solution. Cost reduction is a principal goal of engineering.

Engineering has a special place in the total university R&D effort. Although an engineering department has much in common with basic science departments, the applied nature of much of its work—and particularly its close links with industry—tends to set it somewhat apart. University engineering faculties play an important role in the pluralistic system of research and development, and in particular they contribute to the rapid transfer of technology—either directly or through the students they train for industry. Conversely, these contacts with industry, especially in such new fields as biomedical engineering, electronics, and communications, increase the flow of knowledge from industry to universities. As discussed in Chapter III, there occurred some loosening of the traditional ties between engineering departments and industry in the 1960s, as some engineering departments strove to become more "scientific." But engineering departments on the whole were less likely to insulate themselves from industry than were other departments in the sciences.

Engineering departments enhance not only the research efforts of industry but also those of their sister science departments within the university. Although basic sciences can clearly flourish without engineers on campus, extremely fruitful relations have grown up over the years between engineering and science departments at many institutions, and some universities without an engineering division have suffered. Many university physics departments, faced with declining enrollments, have maintained the size of their staffs by sharing in the teaching loads for large undergraduate engineering classes.

The problems engineering departments face are not entirely like those of basic science departments. Engineers are not only concerned with the use of instruments for precise measurement, they also engage in design and development work and occasionally even manufacture prototype machinery. Engineering research, moreover, may require facilities of a much larger scale than those used in the "middle range" of research in chemistry, biology, or physics. Engineers need wind tunnels and large, specially instrumented water tanks for fluid mechanics research; they require particular working environments (with extremely

well-filtered air, air conditioning, air locks, and a de-ionized water supply) for solid state circuitry work. Such laboratories mean major building modifications, which are especially difficult to finance at present.

An additional problem for engineering departments is the organization of the field. Engineering encompasses a wide variety of disciplines and is organized in different ways at different universities. Some universities choose to have a comprehensive interdisciplinary "umbrella" division or department, although many others divide the engineering division into as many as 10 or more departments, each representing particular disciplines, e.g., aeronautical, astronautical, chemical, civil, electrical, mechanical, nuclear, materials, and environmental engineering. There is as much variation among these engineering disciplines, in terms of approach and kinds of research equipment, as there is among such different fields as physics, chemistry, and biology. At the same time there is considerable overlap in effort and inconsistency in definition so that any attempt to analyze funding trends in separate engineering fields is extremely difficult. For example, more than one third of the federal support of academic engineering research in 1975 could not be classified within the traditional engineering fields.[2]

Trends in Federal Funding

Federal R&D obligations for engineering to universities and colleges by agency for fiscal years 1971-1975 are shown in Table 1. Although there was a dip in such funding for university engineering in 1974, federal obligations have grown from $160 million in 1971 to $211 million in 1975. Some interesting trends can be observed: First, engineering funding from both DOD and NASA has declined in absolute dollars over the period. The DOD proportion of total university engineering funding dropped from 46 percent in 1971 to 28 percent in 1975. Second, NSF has emerged as the largest funder of university engineering research. Third, ERDA, EPA, Interior, and DOT each registered sharp increases, suggesting a stronger engineering focus on energy, environmental, and transportation problems.

Analyzing federal research support by quality of department, as we have done in other fields, is complicated by the fact that Roose-Andersen ratings break engineering into divisions not directly comparable to the departmental classifications used for other fields. Consequently, we are unable to trace the flow of federal funds to specific departments within a broad engineering division or to make any plausible assumption about the relationship between department quality and volume of federal funds received.

The funding patterns in engineering are significantly affected by rapid changes in the fortunes of individual subfields. There have been severe cutbacks in certain subfields: For example, federal obligations to

Table 1

Federal R&D Obligations for Engineering to Universities and Colleges
by Selected Agency, FY 1971-1975

(dollars in thousands)

YEAR	Total	HEW	NSF	DOD	NASA	ERDA	USDA	EPA	Interior	DOT	Other
1971	160,216	10,181	24,310	73,577	31,103	5,004	3,166	1,988	5,867	3,499	1,521
1972	192,993	13,343	52,051	77,809	20,568	4,414	4,052	5,417	7,789	5,607	1,943
1973	203,833	16,314	49,848	85,713	19,079	4,241	5,508	5,018	7,437	9,669	1,006
1974	174,803	16,231	57,389	53,611	14,044	6,400	5,295	6,320	6,919	7,873	721
1975	210,845	17,494	64,239	59,266	16,744	15,589	5,862	8,474	9,926	12,141	1,110

Source: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions*, Annual Publications, Fiscal Years 1971-1975 (1975 publication in press).

universities for astronautical engineering dropped sharply from $16.5 million in 1971 to less than $1 million in 1975.[3] Even though total engineering research dollars have been increasing, researchers have clearly had to "scramble much more for funds and to be extremely agile in keeping up with changing fads," as one senior engineering faculty member commented.

The National Science Board has estimated that basic research expenditures per engineer in doctorate-granting institutions have declined in constant 1967 dollars from $12,600 in 1968 to $9,600 in 1974.[4] While the point is difficult to document, research teams in highly ranked departments appear to have maintained their levels of research support, even though competition for funds has become more intense. The comments of the chairmen of two highly ranked electrical engineering departments are characteristic: "The department, in the main, has been successful in obtaining research funding, but there have been serious frustrations due to changing agency interests, reduced agency funds, and increased reporting requirements." And "Our good people can still get money for basic research."

Unlike the science departments, engineering departments tend to be more dependent on mission agencies than on NSF for research support. Hence, the NSF portion of total research funds is smaller for engineering than it is for mathematics, chemistry, and physics. For example, in 1975 NSF funded 45 percent of university research in mathematics, 36 percent in chemistry, and 35 percent in physics, but only 30 percent in engineering (even though NSF is now the single largest federal sponsor of engineering research).[5]

Many frustrations cited frequently by department chairmen were associated with mission agencies and with rapid shifts in agency interests—the departure from more reasonable practices that in their view used to be the norm. A rupture, or partial rupture, in the relations between the Department of Defense and engineering schools was of particular concern to many engineers. Many attributed changing relationships with DOD specifically to the effects of the Mansfield Amendment. Total DOD funding for engineering research in universities has decreased, and many engineers perceive an increasing emphasis on short-term goals in the remaining DOD funds. The department chairman at a high ranking midwestern engineering school deplored "the sharp curtailment of DOD funding for basic research in engineering." The chairman of another highly ranked electrical engineering department felt that "the Mansfield Amendment is responsible for reducing DOD support in applied as well as basic areas when the time lapse before useful application appeared to be too long."

The Mansfield Amendment, however, is not the only factor encouraging more applied research. Renewed industrial interests in academic engineering have been a significant influence, as have been the practical

and applied priorities of other federal agencies such as ERDA and NSF's RANN (Research Applied to National Needs). Altered research interests of some faculty members also have played a part in shifting the emphasis of much engineering research back toward practical applications. As the chairman of a distinguished eastern engineering department remarked: "We all are more conscious of applications now. The applied areas seem stronger than five years ago [both] because of the heightened desire of the faculty to solve applied problems and because of an increased emphasis on applied work by federal agencies." At a major midwestern university, an engineering department chairman reported that over the past five years, "there has been a sharp drop in DOD basic research and what remains is too narrowly mission oriented; there has also been an increase in NSF/RANN and ERDA targeted research."

It would be a mistake to assume that engineers generally deplore the perceived shift in federal funding patterns toward applications and short-term goals. Although this is true for certain engineering faculty, the opposite view is more widespread. More engineers in universities welcome, rather than criticize, the emphasis on problem solving and short-term applications. Such favorable attitudes were voiced by engineering faculty at institutions of all quality rankings. A number of department chairmen expressed the point in these terms: They complained that engineering in the late 1960s had become "too theoretical," "too 'sciency,'" or "too divorced from industrial application." The chairman of a mechanical engineering department at a southern university summed up the widespread (but by no means unanimous) view as follows: "Engineering schools should not stay in the basic research track that they have been in for the past 10 years."

Graduate Enrollment Trends

A loss of students was the greatest concern of many of the engineering departments visited. As Table 2 indicates, full-time graduate enrollments in fact decreased sharply between 1968 and 1974. This drop is reflected in the fact that between 1971 and 1975 the number of engineering PhDs awarded annually declined from a peak of 3,495 to 2,959.[6] However, full-time master's and doctorate enrollments registered an increase in 1975. The declining undergraduate enrollment may have bottomed out in 1973, for increases were registered in 1974 and 1975. Fluctuations in graduate enrollments have been more pronounced in engineering than in other science fields, making it difficult to assess trends.[7]

Because of insufficient data, no firm conclusion can be drawn on whether the relative proportions of graduate students in higher and

Table 2

Full-Time Engineering Enrollment, by Degree Level
Selected Years, 1965-1975

Year	Freshman	Bachelor's	Master's	Doctorate
1965	79,872	219,717	18,011	9,655
1968	77,484	240,806	24,469	15,768
1970	71,661	231,730	23,216	14,802
1971	58,566	210,825	22,405	14,100
1972	52,100	194,727	22,877	13,460
1973	51,925	186,705	22,588	11,904
1974	63,444	201,099	21,999	10,628
1975	75,343	231,379	26,004	11,281

Source: Based on American Council on Education, Division of Educational Statistics, *A Fact Book on Higher Education: Enrollment Data* (Washington, D.C.: American Council on Education, Second Issue, 1976), pp. 176. 124.

lower ranked engineering departments have changed. Although some highly rated departments have been able to maintain their graduate student numbers, departments at all ranks have experienced enrollment declines. Department chairmen in some smaller institutions expressed the feeling that the loss of quality graduate students would be the most serious factor curtailing their research efforts and that in some cases this could even force the abandonment or curtailment of research programs. Several engineering departments visited were facing the prospect of returning essentially to an emphasis on undergraduate teaching if their decreasing ability to attract quality graduate students continued. At the same time, the number of graduate students in one highly ranked chemical engineering department had dropped by one third since the late 1960s. There are some indications that the enrollment problems may already have peaked, at least for a number of engineering schools. For example, the number of undergraduate engineering majors is reportedly up at almost all the institutions we visited, a development to which the data in Table 2 apparently lend support.

Another development of some note is the expansion of master's degree programs, even at some of the highest ranking institutions. Many institutions visited were either upgrading an already existing MS program, establishing a new one, or reinstating a previously abandoned program. These programs were essentially viewed as "terminal" programs, i.e., they were not intended as recruitment devices or screening devices for the PhD programs.

One of the reasons for declining enrollments at the more advanced levels has been declining industrial interest in PhDs. Industry is still seeking, however, to attract master's level engineers. Several schools

also reported success with programs aimed at attracting part-time graduate students as a way of keeping the faculty busy. Yet many schools are dissatisfied with both the concentration on master's level teaching and the increase in part-time students. The associate dean at one engineering school said that "PhD production has gone to hell" at his institution. Many worry that very little research is possible with part-time students or even master's students, even though faculty size is thereby maintained.

Some institutions have been forced increasingly to rely on foreign graduate students to maintain enrollments and the necessary level of departmental research. In one institution visited, an engineering department reported that foreign students comprised 70 percent of the total graduate student enrollment. However, a range of 15 to 25 percent was more commonly cited in our interviews. Increasingly, major problems are posed for all state institutions with large populations of foreign graduate students. It is difficult to evaluate the credentials of foreign students for admission purposes and to place such students after graduation. More important, perhaps, it is difficult to justify the preponderance of foreign students to austerity-minded state legislators.

Summary of Site Visits

The experience of a highly ranked chemical engineering department provides a striking illustration of some of the problems facing many departments. The number of graduate students in the department has declined by one third from a peak of 95 in 1968. The reason for the decrease, the department chairman believed, was the "publicity about the layoffs in engineering, which sent shock waves through the high schools." Furthermore, many bright students are now leaving without the PhD since that degree is not as desirable in industry as it was a decade ago. Industry has exerted significant pressure to have people stop at the level of the master's degree; the chairman saw this as something new in the last three years.

Two developments seem to be occurring in this department: The number of serious applicants is dropping and bright students are leaving after the master's degree. If the number of graduate students declines below a certain critical mass, some faculty members may have to be cut. The department has encountered the problem of a faculty with research projects but without students to serve as research assistants. To make up for the loss of graduate students, the department has hired technicians—four or five nonstudent research personnel have already been hired—in contrast to no positions of this sort five years ago. The number of postdoctorate researchers is up slightly. The department chairman is cheered, however, by higher undergraduate enrollments—a

30 to 40 percent increase in freshman enrollments in the past two years. Similar though less serious difficulties were present in a number of other engineering departments, yet they were also frequently accompanied by indications of rising undergraduate enrollments.

A few departments have enjoyed a more favorable situation. At a leading western university, applications and graduate enrollments in engineering have gone up over the past several years, as has the quality of students. The chairman of the electrical engineering department reported that, "We have more selection now. The intellectual quality seems a little better, and the motivation is considerably better now than five years ago." This experience was also reported by two leading private eastern universities we visited; they continue to attract an adequate number of very high quality doctoral-level students. At the electrical engineering department of a major and high ranking midwestern public university, graduate enrollment in 1975 was at its all-time high, increasing by one third over its all-time low in 1970. The chairman of this department reports no basic change in the quality of the students so far, but he is worried that "with the restricted financial situation, we expect to be making fewer offers of financial aid in the future, which could decrease the overall quality of our graduate students."

Very different reports are received from chairmen of less highly ranked departments. The following experience was characteristic of engineering departments ranked as "adequate plus" by the Roose-Andersen ratings: A shortage of people for the PhD program is beginning to hurt the research effort. According to the chairman, "The faculty need help. They can't do the research all alone." In 1973-74, there were 36 doctoral students in the program with 6 graduating PhDs. These figures reflect a decline from the boom days when the department in one year turned out 10 or 12 PhDs. The problem, as the chairman sees it, is not so much funding as it is finding a sufficient number of good graduate students. The experience of another department in this category reinforces the point: "We can't get an adequate number of graduate students." This department had 130 graduate students six years ago, and now has only 85. Of these, 65 (or 75 percent) are part time. This chairman was encouraged, however, by the fact that the freshman engineering class is up by 20 percent.

The dilemma faced by an electrical engineering department ranked as "good" may be typical of other intermediate ranked engineering departments in the nation. It built itself up from an essentially undergraduate teaching department in the early 1960s to a research-oriented department by the late 1960s and early 1970s. As of 1976, it faces the problem of a lack of entering high quality graduate students. The best quality students are going to the highest ranked schools. The department does not have sufficient fellowships or teaching assistantships to attract these students. "From 1965 to 1970, we were building up; since

then we have been fighting to keep the hell from being kicked out of us.... No doubt we are accepting poorer quality students than in 1968," the chairman said.

The department's choice now seems to be either to drift back to being primarily a teaching department for undergraduate engineers and first professional degree graduate students, or to change its style of research to one with a "big science" emphasis, using more technicians and postdoctorates in the research effort. The latter course would require them to give up the small-scale, intimate, "one professor and a couple of graduate students" style that has characterized their work. "We're in the process of shifting to more postdoctorates and technicians," said the chairman, "but it's not as successful. It requires more money, larger grants, and I'm not sure we want to diverge that far from our teaching mission."

Trends in Support Services and Facilities

Enhanced relations with industry could help to alleviate the instrumentation problems faced by engineering departments. A consistent theme from our visits, and one with potentially serious consequences, is the deterioration of experimental equipment and cuts in support budgets. The complex facilities required by engineers have particularly high maintenance costs and need frequent modernization. A number of engineering fields have developed to a point where considerations of size, noise, power, or hazard preclude further on-campus research. In many ways industry has a capability that far exceeds anything universities could purchase and/or maintain. Through a cooperative research program, university faculty and students may gain access to such facilities for experimental work, while carrying on theoretical or computer-based activities on campus.

Engineering is largely a "hands on" field of endeavor. Its orientation toward practical affairs keeps it so. Therefore, both teaching and research equipment must resemble in some way those used currently in industry and commerce. Ideally the university engineering research laboratory today should be a forerunner of elements of tomorrow's new plant. For an institution with 10 to 12 engineering departments, a considerable amount of money is required to supply basic facilities such as wind tunnels, distillation columns, structural vibration generators, and autoclaves.

Yet these are merely the facilities in which engineering research is done. Engineering research depends heavily on the use of auxiliary instrumentation—such as sensors, detectors, meters, signal conditioners, and data display or recording systems, e.g., magnetic-tape and computer processors. This instrumentation also frequently includes specialized analyzers, mass spectrographs, electron microscopes, gas chro-

matographs, and comparable devices for which the current unit price ranges between $50,000 and $200,000. Altogether, the auxiliary equipment needed for any modern engineering research undertaking costs about as much as the facilities with which it is used.

Some of the highest ranked institutions visited felt restrained in their research efforts because of the lack or insufficiency of expensive instrumentation, for example, microfabrication equipment, computer systems, and data banks. One leading private university reported special problems in the area of electronic materials and devices, where "the rapid obsolescence and high capital investments for laboratory equipment make it increasingly difficult to compete with industrial laboratories.... We have not had the equipment to fabricate integrated circuits, which has forced an emphasis on materials research as opposed to circuit research."

The chairman of a highly ranked electrical engineering department noted that the availability of capital equipment "was a serious problem five years ago and it is even more serious now. Research is becoming more sophisticated each year and requires modern equipment if meaningful, competitive research is to be conducted. With inflation and the more or less fixed level of individual research grants, it is impossible to request equipment in research grant funds. The deteriorating financial situation at the university has made it increasingly difficult to obtain recovered indirect costs from the university to purchase equipment as was done several years ago."

The instrumentation problem is even more serious for the multitude of small engineering schools, those with perhaps only three or four departments. The cost to them for research facilities is the same per department as at the large schools but the relative cost of instrumentation is considerably more because it cannot be shared over as wide a base. While the equipment problem appears to be a major one for the larger institutions, it is of almost unmanageable dimension for the small engineering schools.

Finally, a major difficulty for engineering, as for virtually all the disciplines surveyed, is that of adequately maintaining equipment once it is obtained. As an engineer at a southern public university told us, "When a once-effective laboratory falls into decay or a new laboratory is not properly equipped in the first place, research-minded faculty have few choices. They can abandon experimental research, start writing surveys and other historical papers to keep up their publication rate, or they can struggle on with decreasingly meaningful research. Whatever result a given choice has on their effectiveness as teachers, the effect on research is disastrous." The chairman of one of the highest ranking departments visited reported that one of his chief difficulties was funding "a maintenance and repair facility on existing grants." A closely related concern is that funds for technical support staff have fallen—in

some instances to a point threatening the continued vitality of the research effort. The chairman of a leading western department felt that the "small-grant method of funding" was particularly inimical to the maintenance of an adequate level of technical help.

Conclusions

Engineering departments appear to share some of the problems facing science departments. For example, many engineers seemed more concerned with administrative difficulties related to funding and funding policy than with the level of funding itself. The escalation of paperwork, the increasingly rigorous demands of financial accountability, and the awkwardness of short-term funding are frequently cited as deterrents to good research and high faculty morale. As an aerospace engineer observed: "There is a common complaint among faculty about the nature of research funding in that it is year-to-year support, and I spend almost as much time renewing proposals as I do working on the research itself."

The engineering department, in a small way, suffers something of the problem faced by the life sciences with respect to an undergraduate "boom" straining departmental resources. The chairman of an electrical engineering department at a public institution was concerned "with student pressure due to more students per faculty member in regular classes, more students at office hours, and more papers to grade." He contended that this directly affected the research output in terms of quality and quantity, and that the increase in undergraduate enrollments "is due to increased pressure on higher education from the state." The engineering dean at another public institution argued that the state government generally believed that "wasting time on research means that insufficient attention is being paid to students. The state thinks we're a community college and an expensive one at that."

Another problem that many engineering departments share with the other sciences is the reduced flow of young people into academic research. An American Council on Education survey of 49 electrical engineering departments indicated that the proportion of young faculty fell from 51 percent in 1968 to 25 percent in 1975, with a further decline to 21 percent projected for 1980. The proportion of young faculty in 41 chemical engineering departments is projected to increase by 1980, but it will still be below the 1968 level.[8] In recognition of the special problems of recent PhDs on engineering faculties, NSF's engineering division established a program of "research initiation grants." In fiscal 1976, 57 grants in the amount of almost $1.2 million were awarded to new PhDs under the program's auspices.[9]

Another manpower trend with potentially serious implications is the decline in the number of doctoral-level graduate students. However,

student enrollments in engineering appear to be unusually sensitive to changing perceptions of the job market, and large fluctuations in enrollment trends are the result. Despite the increases in graduate enrollments witnessed in 1975, it is still unclear whether the drop, especially in doctoral enrollments, has actually leveled off. Engineering departments continue to believe that maintaining doctoral enrollments is one of their most serious long-term problems. The problem is less acute than in some other science fields and new programs in energy and civil sector technology could substantially reverse the trends observed from 1968 to 1974.

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1. National Science Board, *The Role of Engineers and Scientists in a National Policy for Technology* (Washington, D.C.: National Science Foundation, 1972), pp. 9-10. See also Sam C. Florman, *The Existential Pleasures of Engineering* (New York: St. Martin's Press, 1975).

2. Raw data from National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal 1975* (in press).

3. Ibid.

4. National Science Board, *Science Indicators—1974: Report of the National Science Board, 1975* (Washington, D.C.: National Science Foundation, 1975), Tables 3-13, p. 199.

5. National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal 1975*, op. cit.

6. 1971 data from National Research Council, Commission on Human Resources, *Summary Report, 1975: Doctorate Recipients From United States Universities* (Washington, D.C.: National Academy of Sciences, 1975), Table 1, p. 12.

7. For further discussion of manpower trends, see Chapter V, pp. 179-189.

8. Frank J. Atelsek and Irene L. Gomberg, *Young Doctorate Faculty in Selected Science and Engineering Departments, 1975-1980*, Higher Education Panel Reports, No. 30 (Washington, D.C.: American Council on Education, 1976), Table 3, p. 14.

9. Data were provided by the Division of Engineering, National Science Foundation.

V

Emerging Issues in Academic Research

Although findings of fundamental importance continue to be made in the research universities, there is increasing evidence that the strong momentum of America's basic research effort may be slowing down.

Serious issues are beginning to arise in regard to the supporting resources for experimental research in the universities. A second problem is the diminished flow of young scientific talent into academic research. Deteriorating relations between universities and the federal and state governments pose a threat to the research environment as well. Dependence on federal support for project research creates special burdens for universities even while contributing to the strength of academic science.

Chapter V

Emerging Issues in Academic Science

Over the past decade, and particularly since the early 1970s, the number of factors adversely influencing academic science has increased. The most urgent concerns arise from the prospective harm generated by a deteriorating institutional base for research, the declining number of positions available for younger faculty members, a worsening of relations between universities and federal and state governments, and a decline in the supporting services for research, especially scientific equipment. These factors have led to a decreased capacity of many universities to sustain productive research and graduate teaching. Even the strongest universities are beginning to be threatened.

The fact that many findings of great significance continue to be made in every major field, as documented in Chapter IV, does not mean that the future of university research is assured. The discoveries that are now being made are based on research initiated many years ago. The system is operating on momentum, but there are disturbing signs that the strong momentum generated during World War II and for 25 years thereafter has been halted. An important national resource may be eroding and the nation is faced with the possibility that it will lose scientific and technological leadership in many fields. The universities and the scientific community have shown themselves to be resilient. However, most of the easy adjustments—working within an increasingly regulated research enterprise, leaving vacancies unfilled, deferring maintenance, making do with obsolescent equipment—have already been made and further adaptations will be much more difficult. Failure to deal adequately with the long-term adverse trends could generate a decline from which recovery will be difficult and protracted.

SUPPORTING RESOURCES FOR RESEARCH

One major emerging problem that is cause for concern is the decline of the supporting resources that are essential for the continual progress of university research. Prerequisites for success in any research activity are the ingenuity, perseverance, and capability of the individual scientific investigators. But talented investigators need supporting resources to do their work effectively: space, adequate facilities, sophisticated equipment, research supplies, technicians and other personnel, and provisions for the maintenance of facilities and equipment. Although aggregate funding for research in universities has been increasing in current dollars even since the rapid growth in funding ended, and although there is no indication of any major reduction in general support for research by the federal government, the proportion of funds, and in some cases the absolute amounts, going to supporting services for research have been decreasing and the quality of such services has declined. This slow but steady decline in supporting services may have only a limited short-term impact on research productivity, but the environment for research cannot escape substantial deterioration over the next decade if such trends continue.

To a large extent, the university science effort continues to benefit from the infusion of capital resources initiated more than a decade ago. The establishment of such a capital base helped to give the system the momentum that continues to carry research forward. However, since then the supporting services have declined in quality. There is an understandable temptation for researchers to remain working in an area that is passably instrumented and for which research funds are available. But this works against the most imaginative proposals and new research ventures of high promise. As investigators spend increasing amounts of time maintaining and repairing aging equipment, or simply doing without new instrumentation they believe essential to new lines of inquiry, a subtle process of erosion begins to affect the research environment. Aggregate research funding trends disguise these kinds of effects, but one of the most serious issues facing university science over the next decade centers on the factors affecting the quality of the services supporting research.

The problem of supporting resources is actually a cluster of interrelated problems, including the general financial health of the universities, instrumentation concerns, operating costs, major facilities and buildings, technician assistance, and other matters. To gain a full understanding of the problem, it is necessary to look closely at the most significant elements that, taken together, have produced the conditions endangering the long-term vitality of academic research: first, the weakening institutional base for university research support services. We begin with this aspect of the problem not because it is necessarily

the most immediate threat or because it is most amenable to corrective action, but because it underlies all others and must be understood to see the context within which instrumentation needs have emerged.

University Research Support Services: A Fragile Economic Base

The total costs of a university's research effort are rarely assumed by any single source. Federal agencies are the primary sources of funding, but universities themselves typically have expended some portion of their own resources to supplement support from outside sources. The NSF departmental equipment program in chemistry, for example, addresses itself only to part of the total costs of routine use of equipment. As an NSF study on instrumentation, conducted by Cheves Walling and his colleagues at the University of Utah, notes: "The costs of operators, maintenance engineers, parts, supplies, and some updating of the equipment usually far exceed the direct contribution of the NSF in the original equipment grant."[1] Technicians and maintenance personnel, and logistical services such as heat, light, and electric power for equipment operation are the kinds of supporting services the universities themselves have helped to assume. In every case analyzed in the NSF study, there was also "an institutional contribution to the operation of departmental equipment in the form of daily supplies, parts, personnel, etc."[2] This suggests that aggregate figures showing a proportionate decline in federal funds for equipment understate the problem.

In the past, departments and universities were frequently able to supplement grant funds with money of their own for equipment purchase or maintenance or to set up a young investigator with research apparatus. However, the availability of such funds has decreased sharply in recent years; even the most affluent universities have begun to experience difficulties in setting up new investigators. Inflation and the rising cost of complex instrumentation and related maintenance costs, combined with falling endowment income and philanthropic giving in times of economic slowdown, have all played a part in limiting university efforts. Moreover, some of the expenditures that have gone to equipment and facilities have been "defensive" in nature, resulting from government regulations relating to animal care, health, safety, and other requirements. Such regulations have increased the competition for scarce internal university resources.

A recent study of the financial condition of universities by the American Council on Education reports that from 1972 to 1975 universities spent smaller proportions of funds on research. As the data in Table 1 indicate, research-oriented institutions have experienced a decline in ex-

Table 1

Expenditures for Separately Budgeted Research
as a Percentage of Educational and General Expenditures
by Carnegie Commission Categories

Type of Institution	Private Institutions			Public Institutions		
	1972-73 (1)	1973-74 (2)	1974-75 (3)	1972-73 (4)	1973-74 (5)	1974-75 (6)
Research Univ. I	26.9%	26.0%	25.0%	22.1%	20.8%	20.2%
Research Univ. II	19.3	18.2	17.3	18.2	17.4	17.3
Doctoral Univ. I	16.7	16.6	14.8	11.3	11.3	10.8
Doctoral Univ. II	4.9	4.4	4.5	3.8	3.8	3.9
Compr. U. & C. I	3.7	3.8	3.5	3.8	3.4	3.4
Compr. U. & C. II	0.8	0.6	0.8	2.6	2.5	2.4
Liberal Arts C. I	2.2	1.8	1.6	na	na	na
Liberal Arts C. II	1.1	0.7	0.7	na	na	na
Two-Year Colleges	0	0	0	0.1	0.1	0.1

Source: Based on Lyle H. Lanier and Charles J. Andersen, *A Study of the Financial Condition of Colleges and Universities: 1972-1975* (Washington, D.C.: American Council on Education, October 1975), p. 67.

penditures for separately budgeted research as a percentage of educational and general expenditures. Data from institutions in the Carnegie Commission classifications—Research Universities I, Research Universities II, and Doctoral Universities I—all show declining proportions of funds spent on research. This trend has affected both public and private institutions. Although there have been only slight proportional declines in research expenditures over the last three years, the beginning of a slow deterioration in the ability of universities to provide ancillary support for research activities appears to be taking place.

Our site visits confirmed the general picture of gradual deterioration in the instrumentation base. A number of universities have postponed the replacement of equipment and deferred maintenance during the recent period of budgetary stringency. The president of a major public midwestern university noted that the relative need for equipment support had increased over the last few years, but the university had recently decided that equipment decisions would be made at the college level in an effort to get individual colleges to be more selective in identifying their urgent priorities in equipment needs. This policy will likely have the practical effect of making it more difficult for faculty to get their equipment requests approved. At another public institution in the midwest, university support for equipment and instrumentation had

been zero for the last six years, and equipment was obtained only through research grants or outside gifts.

A private university in the midwest with a situation nearly as serious has liquidated its deficit in part by providing no general budget support for equipment in recent years. This same institution has abandoned library acquisitions except those that can be purchased through grants or obtained by gifts. These were the most serious cases of institutional erosion we discovered and the last mentioned was the only institution in our 36 site visits reporting a policy of foregoing library acquisitions. However, library resources have been cut at a number of universities. The engineering dean at a public midwestern institution reported the more typical case: His university supported equipment in the past, but replacement of obsolete equipment is now proving difficult. Technician assistance and equipment maintenance are badly needed, and there is a long waiting period for repair and other services of the research machine shop.

Supply budgets have also been cut because of rising costs. Inflation has particularly affected supply costs for chemistry departments. Chemicals such as acetic anhydride have more than quintupled in price between 1972 and 1975; the cost of trichloroethylene has tripled over the same period; formamide, perchloric acid, potassium iodide, tetrahydrofuran, and sodium acetate cost twice as much in 1975 as they did three years earlier. In one chemistry department at a private university in the West the average unit price of a group of 41 commonly used chemicals increased by 225 percent from 1972-75 (the total cost rose from $19,250 to $58,650) and the average volume routinely used in the department's research increased by over 160 percent. Another chemistry department in a private southern university estimated a 43 percent increase in the cost of supplies over the last year, but the university is increasing its supply budget by only 5 percent.

The economic stringency facing universities affects other research support services as well, as institutions become less able to pay the operating, maintenance, and support costs that sustain high quality efforts in the experimental sciences. A recent survey of 110 responding chemistry departments revealed that maintenance problems with nuclear magnetic resonance machines and mass spectroscopy had restricted instrument usage in 41 percent of the cases.[3]

Even those institutions that are still relatively well off with respect to equipment have begun to experience difficulties as the costs of maintaining superbly instrumented laboratories have risen. One major private university in the Northeast, for example, is planning the consolidation of some academic services by merging two machine shops. Such consolidations may also affect other support services, such as computer facilities and stock rooms. Maintaining machine shops is a particularly vexing problem for many universities, and the specialized

services of technicians are a related urgent concern. For example, both the chemistry and biology departments in a private western university reported the loss of support staff and technicians as a result of the university's budgetary stringency. The chemistry department at another major private eastern university faced a serious problem in providing maintenance for equipment. Getting equipment was relatively easy, but there were difficulties maintaining it and much of it was not efficiently utilized because of inadequate numbers of support personnel. Animal care was another difficult problem in many universities, which often had to squeeze resources out of other support services budgets to pay for the increased costs of animal facilities.

The decreasing amount of flexible university funds also affects supporting research services. Federal grants for major types of instrumentation have ordinarily required matching university funds to pay for one half the cost of the equipment—for example, the departmental instrumentation program in the NSF chemistry division. This matching policy is designed to disperse available federal funds as widely as possible and to secure from the recipient university some financial commitment in order to ensure efficient use of the equipment. However, some universities are simply unable to afford the matching cost requirements, and individual investigators are likely to spend increasing portions of their time trying to find matching funds elsewhere. Federal grants sometimes provide up to 90 percent of the cost of smaller pieces of equipment requested by an investigator, but even the remaining 10 percent may be difficult to come by in the current funding climate.

Emerging Instrumentation Needs

A persistent and critical aspect of the overall problem is the difficulty of updating existing equipment, maintaining instruments in good working order, and replacing obsolete equipment with modern. Although the difficulty varies in severity among fields and among institutions, this is a major concern facing academic science. As current inventories become obsolete in a large number of the nation's universities, the problem will grow increasingly acute. The weakening financial base of the universities contributes to the problem, as do government policies and the short-term incentives for university researchers.

The experimental sciences by definition require facilities and instrumentation to test hypotheses about the physical and the biological universe. Scientific advances in most experimental fields lead to improved data collection and analysis requiring increasingly sophisticated instrumentation and facilities. Large facilities such as particle accelerators and powerful telescopes are dramatic examples of the tremendous capital costs of research, as are wind tunnels, distillation columns,

structural vibration generators, and autoclaves in engineering schools. But the middle range of scientific instrumentation is equally critical to the day-to-day work of research scientists in numerous fields. These "workhorse instruments" of modern science include nuclear magnetic resonance apparatus, various kinds of chromatographic equipment, ultracentrifuges, electron microscopes, isotopic equipment, specialized X-ray diffraction analysis instruments, mass spectrometers, high-speed computers, laser instruments, and scintillation counters. Such items cost from $10,000 to $100,000 each, although some may cost more.

Furthermore, the costs of many instruments have markedly increased. For example, X-ray diffraction analysis instruments have risen from $15,000 to $30,000 over the last decade, and the cost of an electron microscope has gone from approximately $45,000 to $105,000 over the last five years. The acquisition cost of a scanning electron microscope now approaches $140,000 and a specialized Varian XL-100-15 spectrometer is estimated at $190,000.

In some cases, more sophisticated equipment simply speeds up the research process by performing quickly and efficiently the countless repetitive tasks and analyses central to scientific investigation. With a greater degree of precision and speed than ever before, computers can pick out and display significant variations in data generated by experimentation. As computers have assumed much of the mechanical and laborious work of laboratory investigation, researchers are able to obtain and analyze the results of experiments and press forward their inquiries with a speed unknown a decade ago.

Although some types of instrumentation allow more rapid progress in established lines of inquiry, new kinds of instrumentation and facilities also provide for investigation which would not otherwise be possible. With the use of nuclear magnetic resonance spectrometers, for example, the sensitivity of analyzing minute amounts of material has increased from 8 to 1 to a sensitivity of 1000 to 1. Many experiments have sample limitations, and this greater sensitivity requires only one milligram of sample material where older machines required at least a hundred milligrams. The greater power of the nuclear magnetic resonance machines is a key factor in determining the geometry of molecules, leading to experiments in drug metabolism and enzyme studies that bring within reach revolutionary developments far beyond the capability of older machines. Recombinant DNA research provides another example of the importance of advanced facilities and instrumentation in allowing potentially revolutionary investigation. Without the self-contained P-3 laboratories and attendant equipment needed to ensure that such investigation can be safely conducted, recombinant DNA research simply would not take place. Regulatory measures relating to such matters as occupational safety, animal care, protection of human subjects and the like are, of course, another reason for the ela-

borate facilities of modern experimental science.

At times the distinction between speed of investigation and qualitative advances ceases to have practical meaning. Consider, for example, improvements in chromatographic equipment, which in one sense simply make it possible to identify compounds more quickly. Although the absence of new equipment does not deter investigation, the work proceeds more slowly, placing those groups without modern equipment at a competitive disadvantage. However, over the long run, inability to take advantage of improved instrumentation makes a qualitative as well as a quantitative difference. The tremendous advances in computing capacity, made possible by high speed computing equipment, also illustrate how quantitative differences may become qualitative. Sophisticated instrumentation allows researchers to perform investigative tasks more rapidly, freeing them to think of original approaches in their research orientation.

Without the equipment in the middle range of scientific investigation, some lines of inquiry would not be possible at all; in other cases, the quality of the research would retrogress to the level of work a decade or two earlier. Indeed, the definition of the research frontier of a field, and the quality of teaching for graduate students and even for undergraduates, depends upon access to modern equipment. Moreover, techniques evolve so rapidly that a laboratory cannot be equipped once and remain well instrumented without the constant updating, maintenance, replacement, and improvement of facilities. The 1965 National Academy of Sciences report on chemistry (Westheimer Report),[4] which stressed instrumentation needs, did not even mention on-line data acquisition and the minicomputers that now abound in the tens of thousands and other equipment innovations that in the last 10 years have drastically changed the entire experimental approach to chemistry, biology, psychology, and other fields.

This middle range of investigation, so vital to the research enterprise, has undergone severe financial difficulties in the tightened funding climate of recent years. When federal research support grew rapidly from the late 1950s until the mid-1960s, science departments built a base of equipment that helped carry forward the research effort. However, the equipment acquired in that period has now begun to age and wear out in many departments. The difficulty science departments face in updating and replacing old equipment is reflected in the declining proportion of federal funds going to instrumentation over the last decade.

Because HEW (primarily NIH and ADAMHA) and NSF accounted for more than 72 percent of all federal R&D obligations to universities in 1974, the instrumentation funding trends in each of these agencies are significant indicators of equipment support patterns. The National Science Board has reported that the proportion of NIH research project grant funds allocated for permanent laboratory equipment has declined

from 11.7 percent in fiscal year 1966 to 5.7 percent in 1974.[5] The proportion of NSF grant funds spent on permanent equipment has also been in decline. While proportions of NSF grant support spent on personnel, expendable equipment, travel, and publication costs have remained relatively stable since 1967, the proportion of grants spent on permanent equipment has declined from 11.2 percent in 1966 to 7.3 percent in 1975.[6]

The drop in support for equipment may be viewed as a natural outcome of recent trends. When funds are tight, agency officials are tempted to allocate money to support essential personnel costs and to postpone acquisition of new equipment. Investigators, too, have been reluctantly willing to postpone replacement or to neglect adequate maintenance. However understandable the short-run adaptation to austerity, the long-range consequences of a deteriorating equipment base for American science are serious. With a research life of three to six years, middle-range instruments are wearing out and becoming obsolete.

The general picture suggested by the trends in funding for instrumentation and other supporting resources was reinforced by the information gained in our site visit interviews. The problem of supporting resources was consistently cited as a major concern by deans, department chairmen, senior investigators, and research administrators. Although the severity of the problem varied among departments and institutions, with subtle nuances reflecting local circumstances, the set of issues associated with the acquisition, maintenance, use, and replacement of sophisticated instrumentation is clearly an emerging issue of great consequence for university research.

The distinguished departments generally were well instrumented, but even these expressed concerns. A sampling of interview comments gives some idea of the widespread nature of the problem as it is perceived across a variety of fields and institutions and also the slight local variations on the general theme: The vice president at a private university in the South cited the growing obsolescence of research equipment as one of his top two or three concerns, along with the impact of inflation and declining research awards. The chairman of a life sciences department in a private midwestern university declared that "my top priority is equipment, my next priority is equipment, and my third priority is equipment." The vice chancellor for academic affairs at a southern public university saw the lack of equipment funds as "a major concern in chemistry, math, geology, and especially physics." The chairman of the chemistry department at a major northeastern private institution predicted that the availability and stability of funds for general research services, including sophisticated instrumentation, "will be a major factor affecting research over the next ten years." The associate vice president for research at a western public university cited the de-

deterioration of present equipment and the difficulty in getting new equipment as one of the major problems in his institution.

The dean of engineering at a major private eastern institution noted that equipment problems in his school had gotten "much worse" in recent years. The last major infusion of funds for equipment was a foundation grant in the late 1960s that was used primarily for teaching laboratories. He doubted that an equivalent total amount has been spent for equipment since the termination of the grant. Equipment, he said, is "maybe not my first concern but certainly among my top two or three concerns."

The chemistry department chairman at a major western public university viewed the shortage of money for equipment and support personnel as the prime factor affecting research at his university in the next decade. A senior investigator in a life sciences department at a midwestern public university saw the shortage of equipment as a "problem which, unless corrected, will use up the accumulated momentum of a good research institution and will make it increasingly difficult to secure research support." One of his colleagues in the same institution independently concurred that obtaining adequate support for research equipment is a growing concern, declaring that this is "simply an inconvenience at the present time, but unless sufficient support is provided it will become a serious problem." A senior investigator in the physics department at a public eastern university, noting that his department has a major problem in regard to equipment, suggested that he "will have a laboratory full of junk unless more attention is given to this matter."

The interviews also reveal special dimensions of the problem. On the relationship between instrumentation problems and hiring practices, for example, the comment of the chairman of the chemistry department at a midwestern public university was characteristic: "The cost of acquiring and maintaining research instrumentation has not only hindered research activities but is an important factor in regard to additions to the department. I'm hesitant to hire young staff because of the instrumentation requirements."

The increasing constraints resulting from the inability of universities to come up with matching funds are illustrated in the standard complaint expressed by a chemistry chairman from a southern private university: "The requirement that the university match one half of the cost of the equipment [under the NSF equipment grant program] increasingly poses a problem. For example, a mass spectrometer costs approximately $60,000. In the past, the university would have had a 'back pocket' to provide the $30,000 in matching funds, but now it is clear to us that the university does not have such funds. I will now attempt to negotiate one fourth share from the university and will try to provide the remaining one fourth of the funds from departmental re-

sources generated by the Chemistry for Executives Seminar."

The tendency for some investigators to shift from experimental work to theoretical inquiry becomes apparent in a number of interviews, as typified in the observation of an aeronautical engineer at a major eastern private university: "I have switched my major focus to theoretical work. I just don't do experimental research any more."

One of the most worrisome aspects and the source of persistent observations by scientists in numerous fields was the difficulty of getting instrumented for a new line of inquiry. The statement by a biologist from a major western private institution reflects the usual assessment: "It is more difficult to get started in a new field, and this tends to inhibit imaginative thinking simply because there is no point in speculating about what cannot be done."

Operating Costs

Required expenditures for instrumentation do not end with the purchase price of the equipment. Hardware does not operate itself, and costs of electricity, space, operating technicians, replacement parts, and general maintenance are all true costs of a research enterprise with a substantial equipment component. Such costs may not always be apparent, but they are nonetheless real and must be paid. A study for NSF on instrumentation centers in chemistry pointedly concluded that "...the naive concept of free instrumental services needs to be exposed for the nonsense which it is."[7] As an illustration of the operating costs of a sophisticated piece of equipment, the authors of the NSF study included a financial worksheet that contains estimates of the operating costs of a "Varian XL-100-15 spectrometer equipped for FT operation, multinuclei capability interactive disc, and with an acquisition cost of $190,000." Annual personnel costs for time directly related to this instrument are more than $60,000; yearly operating expenses, including routine supplies and instrumental improvement, are almost $14,000; and overhead costs are more than $37,000. The authors note: "From the data...it is seen that capitalization costs amount to approximately 25 percent of the yearly operating expenses."[8]

Major pieces of equipment and instrumentation can provide services to a variety of investigators working on individual projects. However, the common use of a single machine can present severe problems in the allocation of individual user costs. Practices vary widely, but user costs have typically been underestimated by principal investigators. Walling and his colleagues report that "understandably, routine services, the details of which are difficult to document in a proposal, seldom attract or are given the full importance they may deserve in instrumental requests."[9] Nonetheless, the perception that use of an instrument already in place is "free" or very low in cost is an illusion that ignores or dis-

guises the true costs of research. Again, it is instructive to note the conclusions of the NSF chemistry instrumentation study: "The actual costs of operating sophisticated NMR and mass spectrometry equipment have been commonly underestimated by the chemical community.... Without exception, the centers and laboratories investigated by the authors substantially subsidize costs of instrumental analyses which they supply. We strongly recommend that changes be developed in funding patterns which will acknowledge these deficits and provide for the true costs of such services."[10]

Given the increased difficulty of getting grants, the impact of inflation, and the generally tighter funding climate in universities, individual investigators may be understandably reluctant to request in their grant proposals more adequate provision for the true costs of using the instrumentation necessary to their work. Yet disguising such costs burdens the research environment by simply pushing costs along to another part of the system. As instrumentation grows more complex and expensive, the need to devise an effective system for allocating user costs becomes apparent.

Large-Scale Facilities

The large-scale facilities at national laboratories have also faced the problems of equipment maintenance and supporting research services that plague the smaller scale campus laboratories. Generalizations are difficult because of the great variety of conditions prevailing at the national laboratories. But there are some characteristic concerns. The services of technicians and support staff have been reduced at many installations. Visiting teams or user groups are themselves less able to supply the affiliated personnel to make the most effective use of facilities. According to one estimate, budgetary limitations have forced some accelerators to cut their operations to 50 percent of capacity. One observer notes that "because electrical power represents 10 to 15 percent of the costs of operating a large accelerator and the training costs are largely fixed, budget cuts can often be achieved only by turning the accelerator off part of the time."[11] The impact of inflation combined with a generally tighter funding environment has forced economies in operation. As one physicist put it, "We're living in a different style. It's not an optimal one for doing physics, but we're getting it done."[12]

Although much of the frontier research in particle physics and astronomy takes place at national facilities, smaller scale facilities for research in these and other fields continue to exist on university campuses. For example, national installations such as the Kitt Peak National Observatory in Arizona provide an important share of the observation time for university optical astronomers; yet there are many smaller facilities located at individual universities that play an impor-

tant role in the total research effort in the field. Universities have found it increasingly difficult to maintain telescopes; as costs have gone up, machinery has not been maintained, and new ancillary equipment has been needed to use in conjunction with the instrumentation already in place. Concern exists that many of these instruments will gradually become unusable or will be shut down.

The increasing costs of research facilities and attendant services will most likely lead to greater cooperative use of facilities among groups of universities and within universities. For example, a special committee reporting on the long-range educational objectives and academic planning for the University of California recently recommended "a general policy which would require that the acquisition of any new large facility or item of equipment—defined...as costing more than one million 1975 dollars—not be acquired by the University, regardless of the sources of its funding, until the possibilities of establishing it for multi-campus use have been carefully considered."[12]

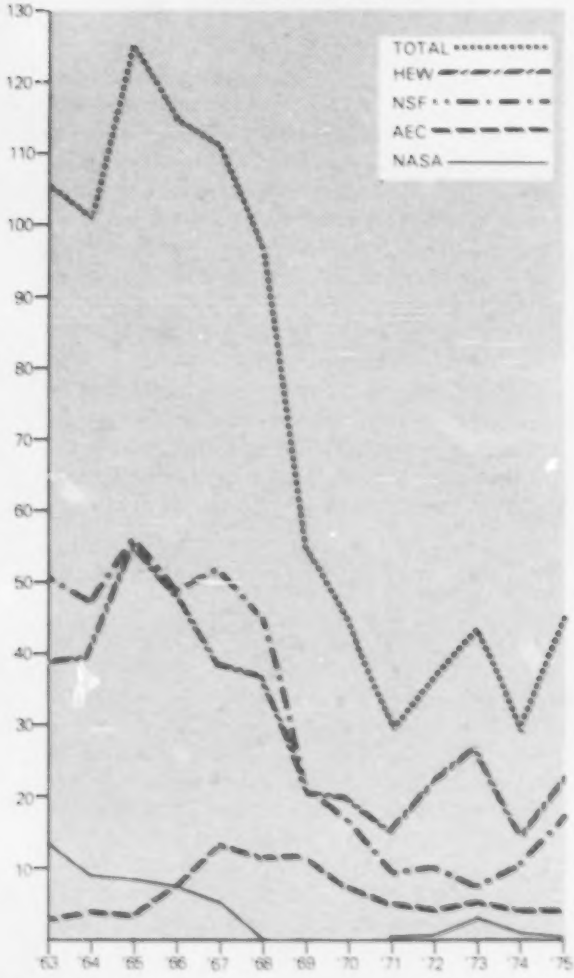
Lack of computer facilities is a growing concern, though practices differ so widely from institution to institution that no simple description of the problem is possible. However, it is likely that in the coming decade computer facilities will be shared among user groups of universities. In similar fashion, research libraries in the future may also rely on either centralized or regionalized data sources with individual campus facilities tied into a larger system.

The Decline in Capital Investment

One final aspect of the overall problem is the decline of capital investment. During the 1960s, institutions of higher education experienced enormous growth in physical plant and capital facilities to accommodate burgeoning numbers of students. Research universities shared in this expansion, as new buildings and research laboratories were constructed. However, by the late 1960s, the period of unprecedented growth had come to an end. The availability of capital funds from all sources has declined sharply over the past decade—a much more dramatic decline than the gradual slowing down of direct research support. It would have been unrealistic to expect capital programs to continue at very high levels even in the absence of a more contracted funding environment. Nonetheless, the decline has proceeded so rapidly and has reached such levels that a serious problem with respect to facilities may emerge within the next decade.

After the launching of Sputnik I in 1957, the federal government became an important source of the capital funds that built up the physical base for university research. This effort reached a peak in 1965, when the federal government obligated more than $126 million for R&D plant in colleges and universities. As Figure 1 shows, federal funds for R&D

Figure 1
Federal Obligations to Universities and Colleges
for R&D Plant,* by Selected Agency
FY 1963-1975
(dollars in millions)



Source: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year 1974: Detailed Statistical Tables, Appendix B*, NSF 75-325, Table B-1, page 2.

*NSF defines R&D plant as "all projects whose principal purpose is to provide support for construction, acquisition, renovation, modification, repairing, or rental of facilities, land, works, or equipment for use in scientific or engineering research and development." A facility is defined broadly to include any physical resource important to the conduct of research or development. All costs – direct, indirect, or related expenditures – are included.

plant dropped to a low of $29 million in 1974, a decline of 77 percent over the 1965-74 period. In 1975, the level of federal funding picked up slightly to $44.8 million. HEW and NSF have been the principal agency funders of R&D plant on the nation's campuses, and each of their R&D plant programs registered sharp cuts from 1965 to 1974 (but increased again in 1975). The funding patterns of NASA and ERDA reflect similar proportionate declines. Currently, except for the construction of national cancer centers sponsored by NIH, there are practically no major federal R&D plant programs.

The large federal investment in R&D plant in the 1960s is being eroded at least partly because of unrealistic allowances for universities in indirect cost recovery for use of capital facilities. Present regulations typically call for use charges of 15 years for equipment and 50 years for buildings. A higher rate of return on capital investment could be obtained if universities used detailed depreciation schedules. Present regulations prevent this, calling for schedules to be applied uniformly to all buildings and equipment within certain classes. The universities are in a position analogous to that of a company using inadequate depreciation rates. Capital facilities are being consumed in R&D activities but replacement is not being adequately funded. Use charges should be allowed to reflect useful life more accurately—possibly as short as three to five years for some types of scientific equipment. The more detailed accounting procedures required by such an adjustment to the present regulations and possible effects on the overall university balance sheet should not forestall the adoption of a more flexible set of guidelines.

Nonfederal sources of capital support, which have also been responsible for building the university research base, have also declined.[14] These nonfederal sources include state governments and nongovernmental funders such as industry and private donors. While no reliable data are available to specify the extent of the practice, it is undoubtedly the case that many states have shelved plans for new construction and major renovation as part of tighter financial conditions. On our visits to 22 public institutions in 15 different states, we found little indication of current construction. State legislators and other state officials as well as university administrators are more inclined in difficult times to maintain programs and necessary current expenditures while postponing new capital expenditures.

The private research universities have typically depended to a substantial degree on private donors for capital programs. The Council for Financial Aid to Education has recently noted that the proportionate and absolute amounts of voluntary support for capital purposes in higher education have been in decline. The amount of voluntary support in this area dropped from $822 million in 1972 to $655 million in 1974-75. The Council reports that "prior to 1969-70 capital giving accounted for more than 50 percent of total voluntary support." However,

that proportion declined from 47 percent in 1972-73 to 39 percent in 1974-75.[15] Foundations, nonalumni individuals, corporations, and religious organizations have each cut the proportion of their support. Of all the purposes for which voluntary support is given, only that for physical plant has declined in both absolute and relative terms.[16]

Projected capital outlay in the late 1970s and early 1980s to all U.S. institutions of higher education will be less than half of that expended in the late 1960s. For private institutions the projections suggest that in the coming decade capital outlays will be less than one third of what they were in the late 1960s.[17] Although a substantial physical plant for research currently exists on the nation's campuses, the downward trends in capital investment suggest potentially acute problems for the near future in maintaining aging facilities and in overcoming obstacles to the building of new facilities. Good research can be, and of course often has been, conducted in less than adequate facilities, but deterioration is a cumulative process and one that is costly to reverse beyond a certain point. The nation's capital base for university science must be sufficient to maintain the facilities that were constructed a decade ago and to allow for a modest increase in the level of new construction.

The Implications of Deteriorating Support Services

The supporting resources for research are as heterogeneous as the basic research effort itself. Such resources include buildings, laboratories, middle-range instruments, research supplies, operating costs such as heat, light, and support personnel, and large-scale research facilities. Each of these supporting resources presents its own set of problems. Many fields of modern science require more highly instrumented laboratories and more space than was considered adequate in the past. Yet recognition of the importance of supporting services has lagged. Building and construction programs have been sharply reduced. Funds for middle-range instrumentation are more difficult to obtain than they were before, and the financial pressures on universities have led to cuts in supplies, operating and maintenance budgets for research, and laboratory renovations. Harvard Faculty of Arts and Sciences Dean Henry Rosovsky summarizes the problem this way:

> Among the many research areas covered by our faculty, none faces a more problematic future than the experimental sciences.... Capital costs are rising very rapidly, not only because of escalating construction and energy charges but also because advanced research is dependent upon the acquisition of newer and more sophisticated equipment and the recurrent modernization of facilities. In addition, government-imposed standards for the conduct of research often require sizable expenditures. The problem of high fixed costs is compounded by the fact

> that government allocations for the maintenance and modernization of facilities have virtually ceased. Given the inflexibility of these costs...it is far easier to reduce the number and level of research projects.... Our resources are hopelessly inadequate.[18]

Few academic science departments have been left untouched by the problem of providing supporting research resources. Some departments are able to obtain sophisticated new equipment but have difficulty finding adequate operating and maintenance funds. Other departments are housed in new buildings but have little support for movable equipment. Still others have adequate research grants but are housed in old buildings with limited research space.

It is important to note that some of the difficulties spring less from limited funds than from inadequate use of resources already available. Investigators may be reluctant to share instrumentation, new equipment is sometimes inefficiently utilized, the transfer of older equipment or its resale to other researchers does not take place on an adequate scale, and conflicting personalities and institutional loyalties interfere with the cooperative use of facilities and instruments.[19] Effective systems for allocating user costs of complex middle-range instrumentation are rare in universities; these will need to be devised in the future. The extent and impact of such obstacles to the efficient use of existing resources cannot be easily documented, but additional funding alone in the absence of improved management techniques is not an adequate solution.

We believe that the maintenance of the supporting resources base for scientific research should command the urgent attention of policy makers. As the costs of experimental research rise, the instrumentation crisis that is beginning to develop in many fields becomes more acute. Special efforts are needed to deal with the problem. The aim should not be a vast expansion, such as that which occurred in the buildup phase of the nation's academic science effort. Rather the goal should be judicious replacement and maintenance of existing facilities with some modest additions. The goal should be to restore to approximately the 1966 level—11 percent of project funds as contrasted with the current 7 percent—the proportion of project funds for laboratory equipment. An indication that the problem has been recognized may be noted from the fiscal year 1978 NSF budget request submitted to Congress, which contained a significant increase for instrumentation. Dr. Richard C. Atkinson, acting director of NSF, observed that "nearly $28 million of the [requested increase] will be used to upgrade instrumentation, equipment, facilities, and research resources in chemistry, physics, biology, materials research, and engineering and in the astronomical, atmospheric, earth, and ocean sciences."[20]

The important steps that need to be taken include the following: Federal granting and contracting agencies should take heed of the deterior-

ation of equipment and facilities in grant requests. This may require some reallocation of funds from other areas, including summer salaries in some cases, to assure that sufficient attention is paid to facilities. Rigid rules on such matters should be avoided; program officers close to the granting process can make the best determination. To arrest the deterioration in the instrumentation base of U.S. academic research, a new program broadly earmarked for instrumentation needs, including upkeep and maintenance as legitimate elements of the program, deserves strong consideration.

The requirements for facilities are of different kinds, each of which requires careful thought and separate treatment. As noted earlier, of special importance are such workhorse laboratory items as nuclear magnetic resonance apparatus, various kinds of chromatographic equipment, ultracentrifuges, electron microscopes, isotopic equipment, specialized X-ray machines, and the like. Such instruments are deteriorating and becoming obsolete. Funds for this equipment should be incorporated in requests for project research funds and given priority according to that of the research to which they will contribute. In the competition for funds, consideration might be given to the efficiency with which equipment will be used, including arrangements for shared use. While it is very important to protect quality and to keep top-ranked laboratories well instrumented, it is also important, given the severe problems affecting many good and adequate departments and investigators, that equipment not be "hoarded" by any departments or investigators. Without adding burdensome reporting requirements, funding agencies should require investigators to indicate in project progress reports the utilization of expensive items of equipment. The mere existence of such a requirement would deter some investigators from asking for unnecessary equipment and would encourage the maximum practical usage of adequate instrumentation for advanced experiments.

Many university buildings used for research require renovation and modernization. Developments within various fields of science now require larger laboratory space and often generate the need for extensive structural additions or changes. Support for such remodeling should be granted on a strictly competitive basis with careful attention to the contributions that the proposed changes would make to scientific productivity. The Office of Science and Technology Policy should concentrate its attention at an early stage on the development of such programs by the agencies supporting the bulk of academic research. Again, we stress that universities cannot and should not expect expansion of physical plant of the sort that occurred in the 1960s. The realistic aim is not major new expansion but maintenance of an adequate base for the nation's academic science effort and replacement of distinctly inferior or outmoded facilities.

MANPOWER PROBLEMS

Persistent and complex manpower issues also threaten the research capacity of universities. The vitality of the research system depends on a constant infusion of young talent. Age is, of course, no certain predictor of productivity, but a consistent flow of new talent into the research environment nourishes the research effort and vitalizes the entire system. Demographic trends, changing funding patterns, and an end to departmental expansion have begun to constrict the flow of young investigators into the system as new PhDs face a declining number of tenure track openings in academic departments and fewer graduate students elect to enter certain scientific fields. The decline in research opportunities for young investigators will be one of the most serious threats to the momentum of university research over the next decade. There is some indication that the sharp drop in graduate enrollments may have stabilized, having begun to reverse itself slowly after 1974, but this is not yet certain.

Factors Limiting the Flow of New Talent

In the post-Sputnik period of expansion, several trends combined to produce unparalleled growth in American higher education. Large increases in federal funds for research in universities, burgeoning numbers of students, and the willingness of state legislatures to expand public institutions—all combined to create an atmosphere of growth and optimism. The era of expansion itself set into motion interlocking manpower forces, which in turn increased the number of research personnel. The growing number of undergraduates spurred faculty expansion, and larger graduate student enrollments provided more teaching assistants to service undergraduate course demands. As departments grew to accommodate the increasing number of students, additional academic openings became available to absorb the new PhDs.

By the late 1960s, however, this set of conditions began to break down. The growth rate of undergraduates slowed, and the number of graduate students stabilized or declined in some disciplines. Estimated full-time equivalent undergraduate enrollment in all institutions of higher education increased by 13.5 percent between 1964 and 1965, but between 1973 and 1974 the increase slowed to 3.3 percent.[21] Between 1970 and 1974, graduate enrollment dropped by almost 18 percent in the physical sciences. In engineering it fell by nearly 16 percent between 1970-73 but registered a slight upturn in 1974.[22] The leveling off of federal funds for university research, the rapid decrease of fellowship support, and an unfavorable economic environment for institutions of higher education have contributed to the declines.

Table 2

Percentage Increase in Bachelor's Degrees by Subject Area
1963-1964 to 1973-1974
and Projected to 1983-1984

	1963-1964 to 1968-1969	1968-1969 to 1973-1974	Projected 1973-1974 to 1983-1984
Social sciences	85	28	1
Psychology	121	79	47
Humanities	75	28	7
Mathematical sciences	44	8	12
Engineering	23	4	3
Physical sciences	23	0	(14)
Biological sciences	55	33	10
ALL FIELDS	56	34	5

Source: Allan M. Cartter, *Ph.D's and the Academic Labor Market* (New York: McGraw-Hill © 1976), p. 227.

Projecting future trends is, of course, highly difficult given the number of unknown factors. Retirement policies, student/faculty ratios, and changing salary differentials among research universities and between universities and other performers are some of the factors likely to shape academic employment patterns and the recruitment of new academic scientists over the coming decades. Undergraduate enrollment patterns will clearly be a key factor, although different sets of assumptions will produce varying projections of future student demand. Table 2 summarizes the available evidence on future undergraduate enrollments. Allan M. Cartter projected here that overall undergraduate enrollments will decline beginning in the early 1980s and that "the most likely magnitude of the net decline [in FTE enrollments] is about one half million."[23]

One consequence of the unprecedented expansion of the 1960s has been that many departments now have large numbers of relatively young tenured faculty. However, with little or no expansion ahead and replacement demands relatively low, the median age of university scientists will rise steadily over the next decade. The median age of science and engineering faculty in doctorate-granting institutions has already increased from 41 to 44 years between 1969 and 1973.[24] What is more, as departments continue to adjust to a steady state environment, new PhDs face the prospect of fewer academic positions.

There is another perspective on the problem: that the scarcity of tenure track openings is only temporary. Harrison Shull, professor of

chemistry at Indiana University, has argued, for example, that the tenure problem "is not as serious as many think." He maintains that early retirement plans, continued high undergraduate enrollments, and a projected high retirement rate that should peak toward the end of the next decade will all contribute to lower tenure ratios. In his view, however, stringent hiring and tenure standards must accompany such developments if imbalances in tenure ratios are to be redressed.[25]

Interpretations of the data on future enrollment trends, tenure ratios, retirements, and other measures continue to be the subject of lively controversy. Our site visits convince us that, whatever the aggregate data patterns, the problem of limited openings for young scientists in academic employment is genuine. Even where academic openings exist on paper, it grows more difficult to convince central administrators that retired or resigned positions should be filled (as opposed to letting them lapse or having them revert back to a central pool). There is a tendency, traceable to state pressures in some instances, to think that stationary or declining enrollments should mean a reduction in staff. Early retirement plans, in the relatively few universities that have experimented with them, have not worked effectively. Cartter perhaps summarizes the situation most succinctly: "Only after 1990 is there likely to be a significant recovery in the number of academic openings available and in the 1980s probably less than one in five PhDs are likely to find academic positions."[26]

Again, it is important to recognize that differences in fields will modify overall assessments somewhat. Graduate enrollments have declined in some disciplines, particularly physics, mathematics, and to some extent chemistry, while enrollments in other fields—especially the life sciences—most likely will continue to grow, although at declining rates. In any event, the flow of young faculty into departments will be much more limited over the next decade in a number of fields, especially in the physical sciences, and universities can no longer rely on expansion to ensure the infusion of young faculty that departments enjoyed in the 1960s.

Table 3 shows the proportion of young faculty (defined here as being within seven years of the doctorate) in 450 departments over 7 disciplines between 1968 and 1975, and the estimated proportion in 1980. All disciplines shown had a lower proportion of young faculty in 1975 than in 1968. The overall proportion of young faculty studied dropped from 43 percent in 1968 to 27 percent in 1975. Significantly, declining academic opportunities for young investigators are likely to continue. Every discipline except chemical engineering is expected to have a lower proportion of young faculty in 1980 than in 1975.

Effects on Research Productivity. The effects of the reduced number of young investigators on research productivity are difficult to assess with any precision. However, in numerous interviews faculty members

Table 3

Full-Time Doctorate Faculty and Young Doctorate Faculty: All Departments Providing Data for 1968, 1974, 1975, and 1980 (Estimated)

Field	Number of Depts.	Spring 1968[a]			Spring 1974[b]			December 1975			1980 (Estimated)		
		Total Number of Faculty	Young Faculty		Total Number of Faculty	Young Faculty		Total Number of Faculty	Young Faculty		Total Number of Faculty	Young Faculty	
			Number	Percent of Total		Number	Percent of Total		Number	Percent of Total		Number	Percent of Total
Biochemistry	17	222	68	30.6	287	56	19.5	277	55	19.9	303	56	18.5
Biology	26	492	150	30.5	578	157	27.2	587	166	28.3	651	153	23.5
Chemical Engr.	41	401	162	40.4	430	99	23.0	428	80	18.7	507	138	27.2
Chemistry	84	1,892	670	35.4	2,051	431	21.0	2,055	417	20.3	2,185	398	18.2
Electrical Engr.	49	1,055	541	51.3	1,137	310	27.3	1,169	294	25.1	1,301	269	20.7
Mathematics	53	1,788	921	51.5	2,010	713	35.5	2,021	607	30.0	2,186	585	26.8
Physics	59	1,460	592	40.5	1,493	300	20.1	1,498	270	18.0	1,570	234	14.9
Other[d]	121	2,483	1,099	44.3	2,781	1,058	38.0	2,844	1,002	35.2	3,079	900	29.2
ALL FIELDS[c]	450	9,793	4,203	42.9	10,767	3,124	29.0	10,879	2,891	26.6	11,782	2,733	23.2

[a] The source of the 1968 data is National Science Foundation, *Support and Research Participation of Young and Senior Academic Staff, 1968*, NSF 68-31 (1968).

[b] The source of the 1974 data is National Science Foundation, *Young and Senior Science and Engineering Faculty, 1974, Support, Research Participation, and Tenure*, NSF 75-302 (1975).

[c] The fields of botany, geology, and zoology were not included in the 1968 NSF study; mining and mineral engineering was not included in the 1968 or the 1974 NSF study.

[d] This category includes the fields of economics, microbiology, physiology, psychology, and sociology. In the original table, these fields are listed separately.

Source: Based on Frank J. Atelsek and Irene L. Gomberg, *Young Doctorate Faculty in Selected Science and Engineering Departments, 1975 to 1980*, Higher Education Panel Reports, No. 30 (Washington, D.C.: American Council on Education, August 1976), p. 14.

expressed their concern that the absence of new blood would be stultifying. As one physics professor put it, "I know what everyone in this department thinks about the research subjects that interest me, and the thought of having no new colleagues to talk with is chilling." Faculty members in a large university mathematics department were so worried about the lack of new faculty positions that they convinced the dean to let them trade 25 graduate teaching assistantships for three new assistant professorships. In response to an NSF survey of the research community's concerns, a physics department chairman declared that "funding of fundamental research can always be increased, but once a researcher begins to decrease in productivity, it is doubtful that the same aggressive attitude of earlier years can be rekindled."[27]

Not only has the proportion of young faculty in academic departments declined since the late 1960s, there is some feeling that tighter funding may have made it disproportionately difficult for these young investigators to obtain research grants. The evidence on this issue is mixed, and no simple generalization accurately describes the situation for young researchers in all disciplines. For example, a study of the social and behavioral science programs in the National Science Foundation reports "a generally consistent pattern...of declining support for young researchers, particularly in psychology and sociology."[28] On the other hand, data on NSF chemistry grants indicate that the success ratio of established investigators has fallen more precipitously than that of young scientists and that since 1970 the young have been more successful than established investigators in getting renewal proposals funded.[29] Moreover, analyses of grants from NIH and the National Cancer Institute show a higher percentage of grants being made in response to proposals from younger investigators than to proposals from established researchers.[30] In response to NSF surveys, 577 department chairmen were asked to indicate whether they believed the split of research funds between young and senior faculty was appropriate. The positive responses increased from 68 percent in 1968 to 73 percent in 1974.[31]

Such evidence, however, does not alter the fact that young investigators must work in a far less encouraging research environment than the expansive one enjoyed by their counterparts a decade ago. Flexible funds are not so readily available; in the physical sciences fewer graduate students are around to assist in research; universities are less able to provide start-up funds; and the competition for external grants has intensified. More demanding tenure standards have created obvious pressures of their own. It is unquestionably much more difficult for the young to establish themselves now than it was 10 years ago, but this is a result of the steady state environment for research rather than of systematic discrimination against the young by granting agencies.

Differences in Tenure Ratios

One concern about the restricted flow of young doctorates into the research system is that high tenure ratios mean reduced flexibility. What are the facts? The faculty tenure ratio in all fields increased from 47 percent in 1969 to 65 percent in 1973.[32] Of course, tenure ratios are likely to differ among fields and institutions, given differences among institutions in policies toward expansion, student enrollment demands, and tenure. An NSF survey of 1,366 science and engineering departments reports that tenure ratios in 1974 varied among fields, from a low of 59.1 percent in physiology to a high of 80.7 percent in chemical engineering, with an overall ratio of 70 percent.[33] Moreover, tenure ratios tend to be higher in public than in private universities.

A survey by the American Council on Education reports that 42 percent of 86 responding public universities had tenure ratios in excess of 61 percent in 1974.[34] The NSF survey of young and senior science and engineering faculty also reports differential tenure ratios among public and private institutions. In 1974, according to the survey, just over 65 percent of science and engineering faculty in private institutions enjoyed tenure, while the overall tenure ratio in public institutions ran almost 72 percent.[35]

Such differences among institutions should not be surprising; the most significant growth in student numbers over the last decade occurred in public institutions. For example, estimated FTE undergraduate enrollment in public institutions increased by 123 percent between 1964 and 1974, while such enrollment in private institutions increased by only 29 percent over the same period.[36] The link between student enrolments and higher state appropriations at public institutions led to rapid increases in faculty; often, in the competition for faculty, tenure was granted liberally.

The private universities also expanded in response to mass higher education, but not so rapidly as the public institutions. Higher tuition and admission standards limited the enrollment growth of the private universities, making their adjustment to the recent slowdown somewhat easier. In addition, the private universities were partially insulated from the aging problem by their continuing policy of maintaining lower tenure ratios. A number of science and engineering departments in the distinguished private universities visited for this study had tenure vacancies. However, as noted above, many were unsure how university administrations would respond if they actually sought to fill the positions.

Despite the differences among institutions and fields, the general tendency is clearly toward higher tenure ratios and the flow of young people into the system will diminish over the coming decades even in the private universities. Some of the best private universities have traditionally promoted very few of their assistant professors into tenure

positions, preferring to fill their senior positions with outside candidates. In the past, this policy did not impair recruitment of young faculty, since an assistant professor from an excellent institution usually could find a tenured post at another good university. Now, however, the situation has changed. Some excellent departments report that their most desirable candidates for assistant professorships are declining their offers and accepting posts at institutions that offer better tenure opportunities. Changes such as these are not necessarily bad from the point of view of the national research picture. However, there is growing uneasiness that the career pipelines may be too constricted and that determinants other than excellence are increasingly controlling career patterns.

Trends in Graduate Enrollments

Changing trends in graduate student enrollments will have their own important bearing on future prospects for young faculty and on university science and engineering departments. Table 4 shows enrollments for advanced degrees in the social sciences, health professions, biological sciences, physical sciences, engineering, and education. Among these fields, only the physical sciences experienced declines in enrollments for advanced degrees between 1970 and 1974 (engineering experienced declines from 1970 to 1973 but increased slightly in 1974). NSF reported that graduate enrollments in 7,664 science and engineering departments increased 9.3 percent between 1974 and 1975. But mathematics and physics enrollments continued to decline.[37]

More detailed graduate enrollment data for matched departments in physics, chemistry, and mathematics, as compiled and analyzed for this

Table 4

Enrollment for Advanced Degrees
by Selected Field of Study
Selected Years, 1960-1974

Field of Study	1960	1965	1970	1973	1974
Social sciences	63,700	120,694	188,006	220,831	242,502
Health professions	5,842	8,909	14,242	27,292	30,378
Biological sciences	29,684	49,142	70,492	80,890	86,089
Physical sciences	37,477	56,704	62,785	53,682	51,675
Engineering	36,636	57,516	64,788	54,530	56,037
Education	94,993	150,300	254,473	306,767	328,137

Source: Based on American Council on Education, Division of Educational Statistics, *A Fact Book on Higher Education: Enrollment Data* (Washington, D.C.: American Council on Education, Second Issue, 1976), pp. 76, 118-119.

study by David Breneman, are given in Chapter II and Chapter IV. The data show that total full-time enrollment in matched physics and chemistry departments had declined consistently since 1969 and that there had been a similarly consistent drop in total full-time enrollment in mathematics since 1968. First-year, full-time enrollment in physics and chemistry increased in 1974 and 1975, however, suggesting that the total enrollment decline in these disciplines may have bottomed out. Top-ranked departments have been slightly increasing their share of graduate students in these disciplines, although even these departments have experienced absolute declines in their number of graduate students.

For the physical sciences—the only area to show a continued decrease in the number of graduate students—there are significant consequences. A traditional strength of academic science in these fields is the close relationship between teaching and basic research in the university environment. As the number of graduate students drops, the productive link between teaching and research is loosened. Further, graduate students acting as teaching assistants have helped departments respond to the demand for service courses resulting from burgeoning undergraduate enrollments, especially in public universities. The decrease in graduate student numbers for some departments has meant a smaller pool from which teaching assistants are drawn; thus departments are pressed to alter teaching loads to meet undergraduate course demands.

In some of the universities visited, the decline of graduate student TAs meant the virtual disappearance of small graduate colloquia and seminars (which are excellent research vehicles for the faculty) and the reassignment of senior faculty to undergraduate teaching. In other cases, it was not faculty time for research that suffered; rather, compromises were made at the expense of undergraduate teaching. For instance, sections were allowed to increase from 50 to 1[illegible] students, and assignments were dropped because senior faculty did not wish to spend time correcting papers.

An important point for the future is the degree to which appointments will be based on enrollments alone without regard for balance among subfields or other intellectual criteria. Faculty sizes in academic departments have typically been fairly closely geared to student numbers, but not narrowly or exclusively so. However, as enrollments drop in the physical sciences, current faculty size may become increasingly difficult to justify. Some departments have already suffered contraction, and the central university administration practice of withdrawing lines in the event of vacancies may spread as declining enrollments are cited as justification for cutting faculty size. The matter was expressed most strongly by the chairman of one physics department: "I know they're just waiting for us to die over there. Last year, after a long ill-

ness, one of our members did die, and the glee was almost undisguised. They could hardly wait to grab back the position from us."

In addition to a tight job market, changing federal policies have affected graduate education over the last two decades. The sharp drop in the number of federal fellowships and traineeships since 1968 has contributed to the smaller graduate enrollments in physics, chemistry, and mathematics. The National Board on Graduate Education reported that the number of graduate students supported by federal fellowships and traineeships increased from 15,600 in 1963 to 51,400 in 1968, but by 1974 this number had fallen back to 18,472.[38] The Board's final report estimates that the number of doctoral students with federal fellowship or traineeship support, excluding NIH/ADAMHA training grants, ranged between 3,000 and 8,000 in 1974.[39] Although subject to budgetary uncertainties, the NIH/ADAMHA training grant program continues to be a major supporter of graduate students—despite the planning difficulties attendant on budgetary fluctuations. The future of graduate support programs in the biomedical sciences is unclear since a National Academy of Sciences committee has recently proposed a "modest but significant reduction of about 10 percent in the number of federally funded predoctoral candidates [in the biomedical sciences] from the level that existed in FY 1975."[40]

A principal predoctoral federal fellowship program still in existence is the NSF Graduate Fellowship Program, which annually provides about 500 "portable" awards directly to students. High-ranked institutions and departments are more likely to benefit from such programs since students tend to choose these institutions. A study by the Association of American Universities indicates that 51 percent of the 550 NSF fellows in 1976 chose to pursue their graduate study at one of six schools, and two thirds of all the fellows will do their graduate study at only ten schools.[41] In physics, chemistry, and mathematics, the total number of fellowships has declined sharply; of the fellowships still available in these fields, higher ranked departments have been getting a larger proportion.[42]

As the number of fellowships has declined, other sources of graduate student support have become relatively more important. NSF reports that the number of full-time graduate science students who depend on family or self-support increased by 22 percent between 1974 and 1975. The number of full-time graduate students in doctorate departments who receive research assistantships has increased from 33,040 in 1973 to 35,095 in 1975. The total number of teaching assistantships among graduate students in doctorate departments has also increased over the period, from 38,452 in 1973 to 39,702 in 1975.[43] Breneman reports that in 146 matched physics departments the proportion of graduate students supported by teaching assistantships increased from 28 percent in 1968 to 41 percent in 1975; in 168 matched chemistry departments,

from 38 percent to 53 percent; and in 120 matched mathematics departments from 43 percent to 63 percent.[44]

It is generally conceded that federal fellowships and traineeships in the 1960s may have stimulated production of PhDs in some fields beyond immediate needs. But the abrupt reduction of funds that has recently occurred could cause a jolting contraction in the system. Overreaction against what appeared to be an excessive production of PhDs could, in fact, cause a permanent disequilibrium in the supply and demand for scientists and engineers. The Overview Cluster reporting to the President's Biomedical Research Panel placed great emphasis on the problems facing young researchers in the biomedical sciences:

> ...we wish to draw attention to a single, central, and dominant problem which has been raised in all of the other reports, and which must be solved quickly if there is to be a future for biomedical research in this country. The problem is the next generation of young scientists, who must be here and at work within the next decade.
>
> As things stand, the emergence of this generation is still a matter of doubt. The budgets of medical school departments (and the science departments) of the universities have been effectively frozen during the past two or three years, due to the general economic problems affecting these institutions, the leveling off of research funding from the NIH, and, especially, the elimination of federal support for research training programs. From the point of view of the youngest people, those just entering scientific careers and those just behind them trying to make up their minds, the future of biomedical science looks bleak indeed. There are few job opportunities, and even fewer visible opportunities for advancement to higher positions in the years just ahead. The whole system seems to have become abruptly locked up. Something will have to be done about this situation now, or we will discover sometime in the late 1980s that we have skipped a generation. It hardly needs saying that the scientific enterprise cannot undergo such a loss without serious damage to the future quality of research. It is not widely enough recognized that the youngest people, the ones still in training, are indispensable; they are not only essential for the future, they are also indispensable for the work that has to be done today.[45]

One can envision a future when new training programs may have to be developed suddenly in response to new demands, with resulting inefficiencies similar to the great expansion in PhD programs that occurred in the 1960s. The general need is for a continued, fairly smooth flow of young scientific manpower into a variety of productive careers, not just into teaching and research positions in academic institutions. The system should be responsive to changing needs, but wild fluctuations in the supply of scientists and engineers are disruptive. Although trends cannot be projected with certainty yet, our site visits revealed that many science and engineering departments seem to have stabilized their enrollment levels in graduate programs in the past several years. Perhaps even more significant was the widespread tendency we observ-

ed toward increased freshman enrollments in science courses.

The manpower problems affecting the sciences have numerous subtle dimensions—the flow of young talent into the system, opportunities for young scientists, aging of existing faculty, increasing tenure ratios—and there is no easy way for the government or for universities to affect the overall situation. However, universities clearly need to devote a great deal more thought and attention to the problems. At the center of the matter is the need to ensure a continued flow of the most highly talented young people into the system. Various proposals have been discussed for the federal government to assist in resolving the manpower problem—career development awards, awards to senior faculty so that their salaries could support younger scientists, and other measures. It is not our purpose to examine the strengths and weaknesses of specific proposals. Our feeling is, however, that considerable unrealism has marked the thinking about these issues. Manpower problems are very complex, and they seldom provide a clear basis for federal intervention that could have an immediate impact. However, in our judgment, the number of portable fellowships has clearly become too few. The special advantages of fellowship support need to be recognized.

But few aspects of the overall manpower problem can be so readily addressed by federal policy. The universities themselves must bear the major responsibility for hard thought on manpower issues, for posing clear choices to the public, and for reform of their own procedures. Consider, for example, one imaginative approach discovered in site visits: A major physics department, with 58 tenured faculty members out of 60, was not scheduled for new appointments for some years. The department and the central administration developed a plan whereby the department was allowed to appoint one new assistant professor every other year who would have the usual opportunities for promotion and tenure (approximately 50 percent of the assistant professors traditionally made tenure). In return, the department agreed that it would shrink back in size to approximately 40 faculty members when a number of retirements came due some 10 years hence. This reflects imaginative, long-term thinking of a kind that is all too rare. Widespread acceptance of the idea that faculty size must be rigidly tied to student enrollments will complicate the task of dealing with manpower problems. Universities need to begin pursuing inventive approaches.

DETERIORATING GOVERNMENT/ UNIVERSITY RELATIONS

Few subjects so deeply trouble educators as the sharply deteriorating relationships between government, both state and federal, and the universities. Yet few subjects are so steeped in misperceptions and failures to understand diverse points of view. The dominant impression conveyed in hundreds of interviews with university faculty and administrators during our site visits was one of shock at the apparently sudden and dramatic growth of burdensome regulations over all aspects of university operations, including research. To the academic observer, the university has become bureaucratized virtually overnight. The statement of one department chairman gives some impression of the intensity of feeling in the academy:

> I just couldn't believe it. I was chairman ten years ago and now when I rotated back into the chairmanship the difference was astonishing. It was a pleasant job then; everybody did his work; you had a few ceremonial duties. Now I'm swamped with red tape. There are forms for everything; I am always answering some request. It all comes down to the departmental level because no one else knows who is doing what.

Statements of this sort came from presidents, deans, chairmen, senior faculty, and even occasionally from junior faculty and graduate students (who have, presumably, learned of the purported halcyon days from their elders).

At the government level, official skepticism and irritation toward university spokesmen have escalated. Complaints from universities have struck many government officials as being out of proportion to actual grievances. Congressman John Brademas expressed such concerns when he called for "a little more information and a little less admonition from the higher education community."[46] From the public university standpoint, developments within some state governments are particularly troublesome. Having awakened within the past decade to the need to control educational expenditures, the state governments have greatly extended their scrutiny of public university budgets and activities.

Many of the difficulties that have arisen in government/university relations spring naturally from rapid social and economic changes. Equal access to higher education, nondiscrimination in hiring, protection of human subjects in research, occupational health and safety, and the right of access to confidential files have become urgent social issues only recently.

In trying to cope with new legislation or administrative regulations designed to protect such newly won rights, colleges and universities have come up against serious problems of adjustment. They must also

deal with the extension of familiar pieces of social legislation, such as workmen's compensation and unemployment insurance, to cover their previously exempt activities. As experience is gained in living with the regulatory measures, many of the frictions that have marked recent government/university relations will very likely die down. Experiencing extensive government intervention in their affairs for the first time, universities in some ways have reacted like the business firms of the earlier part of the century.

In any event, the American people strongly support the goals the regulatory measures are designed to enforce. As the law of the land, there is no question that the measures must apply to universities along with other institutions in society even if compliance imposes difficulties and costs.

Although the impact of some measures may prove less onerous than many observers now believe, the relations with government have nonetheless clearly entered a more complex phase. The scope of public intervention has extended into new areas affecting the research activities of universities. The scale and magnitude of government influence, including intervention into the most detailed aspects of internal policy, have reached the point where the traditional autonomy of the universities has been seriously threatened. Although poor communication, inexperienced officials, and misperceptions are partly to blame for worsening government/university relations, deeper and less tractable issues are involved. The nature of the university's relationship to society is questioned along with how it is to be held accountable as the recipient of large-scale public funds.

Distrust has become, in many cases, a guiding principle in relations between university and government agencies. The larger problems that seem most in need of reassessment include: the terms and conditions under which university scientists receive public funds for their work; the requirements by which universities account for the use of research funds; the vexing issue of indirect cost recovery; and the extent to which disparities between state and federal action create special burdens for the university research effort.

Government Support of Research: The Terms and Conditions

Striking changes have taken place in this area. Although for the most part these changes are not the result of sudden or highly visible government actions, nonetheless their net effect has been to alter the climate and character of the grant acquisition process. To some extent the conditions must simply be considered an inevitable cost that accompanies the receipt of government funds. Stating the matter thus is somewhat negative, however, for unquestionably the very exacting and

demanding process of seeking and receiving research support contributes to the advancement of science by enforcing high competitive standards.

Greatly increased competition for federal research support has meant that greater effort goes into the grant acquisition process. As we have noted in Chapter II, there are now more academic scientists and fewer dollars available to them in terms of the units of constant purchasing power. Faced with the task of sustaining the scientific effort in difficult times, federal agencies and program officers have adopted various strategies. While no summary characterization is entirely accurate, NIH in general has tended to maintain the size of its grants or even to increase somewhat the average grant amount to offset the effects of inflation. Consequently the agency makes fewer grants. For all the institutes, award rates (direct cost awarded as a percent of approved amounts) declined from 83 percent in 1967 to 63 percent in 1973. In 1975, overall award rates increased to 70 percent, still below the 1967 level. There are, of course, differences among the institutes. For example, the 1975 award rate in the National Cancer Institute was 82 percent, while the National Heart and Lung Institute had an award rate of 58 percent.[47] NSF divisions have followed no uniform pattern; as noted, chemistry has made fewer grants of larger dollar amounts.[48] But other NSF divisions have tended to hold dollar levels of grants essentially constant and thus to increase the number of grants, as budgets have risen in current dollars. In 1967, the Foundation awarded 3,765 scientific research project grants in the amount of $168 million, and in 1975, 7,019 grants were awarded in the amount of $338 million.[49]

Further, although the point is difficult to document with confidence, there has been a trend toward somewhat shorter grant periods. This has been partly the result of the decline in institutional support that flourished for a brief period from Sputnik to approximately the mid-1960s, but the trend is not simply a reflection of the severe reduction in institutional support. An evaluation staff study of scientific research project support in NSF declared that "there has been a trend toward supporting larger numbers of personnel for shorter durations between FY 1968 and FY 1974."[50]

The emphasis on greater targeting in funding practices, including the shift to the more widespread use of the contract mechanism via the request-for-proposal (RFP) route, is another force contributing to increased competition for grants among academic researchers.

As a result of all these factors, more investigators are spending more time acquiring and renewing grants. As the competition has grown more intense, the pressures to submit more elaborate documentation and supporting materials and to seek additional funding in areas where one already has done considerable research have correspondingly mounted. In the days of OSRD activities during the war, and even in

the early postwar experience of ONR, a one-page letter of understanding often was all the documentation needed to initiate research by the university scientist. But the process has grown much more formalized, the grant or contract itself is much more complex, and the sheer volume of legal obligations that must be assumed has multiplied significantly, imposing hidden costs on the institution as well as the individual investigator.

The lament of the investigator can be illustrated in the following comments from site visits, chosen not for their eloquence, but because they are representative of the feelings of many:

> I have long since ceased being an active researcher. Oh, yes, I hang around the lab a little, but almost my entire effort goes into the process of getting and renewing our grants. (Chairman of a medical school department)
>
> I try to relieve my residual anxieties by publishing something once in a while. Most of my energies, though, go to keeping my team going. I am tired of what I am doing, I would like to branch out a little; but if I stop scrounging to keep this operation going, it would just fold and a lot of people would go down with it, and it might take a year or two before I could establish enough of a reputation in another field to get funded. You always try to bootleg a little, but it's not easy. (Senior professor in a psychology department)
>
> For over two years I waited to get funded. It was agony, but I know how tight money is. I think I am finally set, and I feel very lucky. The hard part was that I couldn't do anything until I had the experimental set-up. I suppose I could have tried to get out some quick theoretical piece to pad my vita. But I didn't want to do that because I didn't think it would be very important. I hope they take the delay into account when it comes to tenure. I think they will. (Assistant professor of sociology)
>
> I really have sympathy for the agency program officials. They are really doing their best, the whole process is very professional. Often they don't know what their budget will be until the last minute. But I wish there were some way it could be speeded up; the process just takes too long. (Senior chemistry professor)
>
> Look, one agency gives me the front end of the fork. Then I have to scrounge to get another agency to give me the back end of the fork. If I could only get some agency to give me a whole fork, I could dig a hell of a hole. (Geophysicist)

Such comments express the hidden costs of the grant acquisition process: the increasing amounts of time investigators spend to acquire research support. Nearly all chairmen interviewed in our site visits reported a marked increase in time spent seeking grants. Senior professors reported similar experiences.

Much of the increased effort to date has simply reflected faculty members' longer hours and harder work. But there are limits to how

much further the process can be pushed without substituting proposal writing for actual research to some significant degree. Such an outcome may appear absurd, but the tendency is already discernible, and the costs may be great. The following consequences were observed on a number of our site visits: the shift away from experimental research involving equipment purchase to theoretical research requiring little or no equipment in order to minimize the struggle to obtain funds; the reduction in the scale of research activities by some investigators who were simply tired of the ceaseless quest for funds; the practice of keeping to a "safe area"—one in which funding is assured—and avoiding the more speculative lines of inquiry that carry higher scientific promise.

The grant acquisition process, in brief, has not merely become more competitive—an unavoidable consequence of a larger number of scientists seeking limited funds—it has also become more elaborate, time consuming, and bureaucratized. Investigators often complained of the mounting documentation required for a proposal. In some instances, the faculty member appeared forced into the position of enumerating all the steps in a complex experiment in such a detailed fashion as to rule out any creative departure from a prescribed path or, alternatively, writing the proposal could become an exercise in dissembling. In addition, there are pressures for more and more documentation as researchers attempt to improve their chances to get a grant, and more elaborate proposals take more time to review adequately. One social science research center has a rule of thumb: Seven proposals must be submitted in order to win one grant or contract. A 1:7 success ratio in the preparation of extensively documented proposals gives some indication of the professional time spent to secure funds.

The substantial time required to negotiate a grant means that the grant applicant inevitably has less time available for normal academic duties. Again, effects on faculty vary, but our site visits uncovered numerous instances of faculty choosing to neglect teaching duties, particularly undergraduate teaching, in favor of grant-getting activities. Indeed, in the case of younger faculty, chairmen in a number of departments noted that they were forced to make an early distinction between assistant professors who were likely to be serious candidates for tenure and those who were not. The individuals with research promise and tenure prospects were given lighter teaching loads to enable them to concentrate on research and the efforts required to gain support. The other younger faculty were given very heavy teaching loads with virtually no expectation that they would get tenure. As one chairman of a major biology department tersely summed up the practice: "Look, it's simple. No young scientist who is serious about his undergraduate teaching is ever likely to get tenure in this department. That's the reality." In summary, the generalization that research enhances teaching

must be qualified to recognize the limits often imposed by the competitive rigors of the scientific career.

Long, frustrating delays in the grant process are to some extent unavoidable, but more expeditious and consistent behavior by funding agencies would help. Such actions need not mean compromising the principle that merit and fair competition shall apply in the selection of winning proposals. Nor do funding agencies, including mission agencies, need to sacrifice their freedom to choose program areas for extramural research support in order to minimize some of the abrupt discontinuities that adversely affect the university research effort.

Federal priorities will always shift, and universities generally recognize the inevitable uncertainty in funding. But some practices are simply unnecessary, and well-known administrative techniques exist that could greatly ease the adverse impact of others. In the former category, the following incident comes to mind: midwestern biologists complained that a research program in biophotolysis was announced and proposals were invited; six months later, after investigators devoted time and effort to proposal preparation, the program was cancelled without any awards being made.

Broader administrative reforms, such as NASA's use of "step funding," whereby a grant or contract is phased out over a three-year period with gradual reductions in funding levels, pose adjustments and difficulties for the funding agency. Such devices, however, are highly promising since an orderly buildup and phase-out of the research effort maximizes the chance for creative research performance under the grant or contract. Arrangements such as this will almost surely be necessary if the nation's leading universities are to become seriously involved with energy R&D or other urgent national needs. Making long-term commitments against short-term and uncertain revenues is hardly an attractive prospect, yet this is what universities are sometimes asked to do. This mismatch of agency and university objectives must be remedied if the nation is to make the fullest use of its most creative talents.

Another dimension of the problem is the apparent growth of rigid and burdensome requirements once an award has been made. There is no easy way to document this trend, but the following brief sample of incidents reported during site visits is illustrative:

> A western physicist reported that it took several months, through numerous administrative levels, to get a decision on charging a $150 calculator to his research grant. (He was finally told that he should either pay for it himself or else ask for a $3,000 instrument.)
>
> A senior physicist from the East wished to use part of his grant for an experiment by a younger colleague. It was a year before permission was granted, delaying the young physicist's work.

A senior engineer from the East remarked that he "would not dream of asking" a program officer to change an aspect of his grant because "it would take six months of hassle and end up with nobody giving a clear-cut answer," which he felt was in sharp contrast to the practices of five years ago.

An eastern assistant professor commented: "We had an awful time with a request for a $2,000 item of equipment. I can understand the need for special rules on computing equipment—that is an area where costs can escalate rapidly because everybody and his uncle wants some new widget—but this was just weird. There has to be a simpler way to handle it."

A senior chemist from the West noted that his colleagues were all "scared" and almost nobody was willing anymore to spend a small amount of his grant to assist a colleague's research. ("Things are just too tight. You can get into real trouble. Sure, there have been abuses, but in the old days you weren't a criminal if, say, you carried a graduate student in another section on your grant for a term during some emergency. Now you wouldn't because his work is just not strictly related to what you're doing.")

An assistant professor of engineering in the East reported that he had a twelve-month grant that required monthly progress reports.

A geophysics chairman from the West remarked that his funding agency recently asked him to Xerox a progress report and send copies to a lengthy list of other grantees in the program area. ("This wouldn't have happened before. It wasn't really so bad, just a minor thing. The world is not coming to an end, but it did tie down my secretary and research assistant for nearly a whole week.")

Universities have certainly been guilty of abuses in the past, and controls imposed by granting agencies almost invariably have their origin in some previous episode that brought critical attention to agency practices. Considered in isolation, many of the rules and regulations are logical and, if properly administered, would pose no hardship for investigators. But what is at issue is the totality of the constraints in the process. Government has seemingly acquired, through the sheer weight of regulations, an unintended degree of control over the substance and direction of the research activities.

Occasionally one even hears frank expressions of federal intent to exercise control on specific issues that bespeak the changed atmosphere in government/university relations—the shift away from partnership toward greater federal direction. As an HEW official recently told the Association of American Medical Colleges: "It is important to see clearly that the direction in which we are moving is toward increased federal domination of the American health enterprise."[51]

Part of the problem of relations between university researchers and federal officials may arise from the difficulty of attracting outstanding research administrators into federal service. Federal salaries have been limited and many government positions frequently have been less at-

tractive than positions within universities. (The pay raise enacted by Congress in the spring of 1977 has remedied the situation to some degree.) Of course, deeper issues of substance and conflicting objectives are also at stake and need to be resolved in a way that protects the legitimate interests of government while giving universities the freedom and flexibility to perform creatively.

Requirements for Financial Accountability

Related to the terms and conditions under which government supports university research are the rules and regulations concerning financial accountability. Frictions here have arisen most directly between university administrative officials and federal auditors. Although the skill of research administrators can shield faculty from the effects of some intrusive forces, our site visits indicate that in most instances faculty cannot be insulated from the impact of accountability requirements. Although the methods of administering research vary widely among universities, the department chairmen ultimately seem to bear a large share of the administrative burdens. This appears to be true whether the institution has a large and efficient project and grants office or a small one doing little other than processing forms and mailing in the proposals. Most of the issues that arise over audit disputes, for example, relate to work conducted in the department, and the department inevitably becomes involved. Frequently the department duplicates the record keeping of the central administrative level even when the central office is well run.

The changeover in audit responsibilities from DOD to HEW has recently posed some acute problems for many universities across the country and particularly in certain regions. Audit disallowances have escalated rapidly, and the normal disputes over the interpretations of detailed accounting requirements have sharpened to an unhealthy point. A large dispute, for example, arose early in 1977 when the federal government asked the University of California to return $5.6 million of federal funds that it contended were improperly attributed as costs under government grants and contracts.[52] An adversary relationship has arisen as university officials and federal auditors negotiate differences in record keeping, compliance with regulations, and the like. In contrast, when federal agencies were building the foundations of their associations with universities, a partnership existed in research even though the audit process was conducted at arm's length.

Researchers at the University of California have analyzed in a series of studies the impacts—both cost and benefit—of a number of different areas of federal regulations affecting the universities' research activities, as those regulations have been interpreted by nine federal agencies. Although the areas studied do not include the entire list of federal reg-

ulations, brief summaries of several of those analyses illustrate the nature and degree of impact of government regulations on the conduct and cost of research:

Cash Flow. In one year, 1973-74, the University of California lost $630,000 in interest because it had to use its own working capital to pay expenses on government-funded projects. The sponsoring federal agencies would provide reimbursement only after evidence of expenditures had been submitted and reviewed. Federal cost-reimbursement policies do not allow lost interest to be reimbursed. Although most government grants and contracts avoid this drain on university resources by providing letters of credit or by paying costs in advance, agencies are not always consistent in this respect. Both the Air Force and HEW had some of their contracts with the University of California on a pay-in-advance basis and some on a cost-reimbursable basis.[53]

Environmental Health and Safety. Federal, state, local, and university regulations all set standards or requirements for environmental health and safety. But some federal agencies also impose additional requirements, and these differ among agencies. In the judgment of the university representatives involved, these add little either to health protection or to research quality. But they do add to the intricacies of contract negotiation and to the number and detail of the required reports.[54]

Property Management. Compliance with regulations governing the management of property purchased with grant funds and of surplus government property used by the University brought a substantial burden of paperwork that could have been avoided in a climate of greater trust. If restrictions on the transfer of title had been raised from $1,000 to $3,000, 60 percent of the items subject to such controls at the University of California, San Diego (where this study was conducted) would have escaped these property management regulations and much of the attendant paperwork. That change could have been made with little if any loss to the government; most of the property involved was later given to the University and was then free of federal record and reporting requirements.[55]

Time and Effort Reporting. Only estimates could be made of the actual dollar costs of reporting on faculty members' time and effort devoted to sponsored research projects. For any one individual these costs were relatively small. For the University as a whole, the annual total was estimated to be about $500,000.[56]

Another long-standing problem is that different federal agencies require different forms and details for receiving essentially the same information from universities. The Research and Development Board of the Department of Defense tackled nonstandard reporting requirements a quarter of a century ago but little progress has been made since then in achieving greater standardization. Such efforts continue, but

most federal agencies still insist on their own individual reporting requirements. In November 1976, HEW created an interagency task force in a new effort to reduce burdensome reporting requirements on universities calling for "radical changes in the paperwork reporting requirements" and for a commitment by each agency and department to "simplify and consolidate" federal reporting requirements.[57]

Universities, as large-scale recipients of federal funds, must account for the use of those funds in the manner prescribed by law. It would be improper to suggest that universities should be subject to any other than the strictest standards of legality and propriety in the use of public monies and in the conduct of research for the government. But the larger aims of the relationship—the achievement of full value for the grant or contract, the most creative effort in the national interest—should not be defeated by excessive zeal in the mechanics of contract administration. Federal agencies could profitably consider adopting "self-denying ordinances" with respect to universities—such as those HEW issued on Title IX of the Higher Education Act Amendments of 1972. HEW took note of the harmful effects of sexual stereotypes in textbooks but decided against extensive efforts to scrutinize textbook materials on the grounds that greater harm would result. The agency's analysis stated the issue thus: "The Department recognizes that sex stereotyping in textbooks and curricular materials is a serious matter. However, the imposition of restrictions in this area would inevitably limit communication and would thrust the Department into the role of Federal censor."[58]

Yet it is perhaps unrealistic to expect that federal agencies will themselves be able to restrain significantly the growth of their supervisory power over university activities. The general issue of how far the reach of federal regulatory power extends over university activities remains unresolved and will constitute a central concern in government/university relations for the foreseeable future. As George LaNoue has summarized: "The problem...is not that there is some grand coordinated federal plot to deprive universities of their autonomy.... Federal control is created instead by the actions of scores of agencies and hundreds of bureaucrats each tailoring alterations to fit their idiosyncratic view of education. The bureaucracy is so decentralized and its regulations often of such low visibility that it is hard to imagine Presidential or congressional action consistently restraining it. Without some constitutional standard, the federal tailors will continue to design the future of American education."[59]

INDIRECT COSTS

Few aspects of the university/government research relationship illustrate the complexity of the issues as well as the indirect cost question—a notorious source of misunderstanding and friction. The issue creates divisions between and among investigators in universities, central administrators in universities, executive agencies, state governments, the executive office of the President, and committees of Congress. Many details of indirect cost computation are extremely complex, and the rationale for inclusion or exclusion of certain costs gives rise to endless debates.[60]

However, the essential elements of the problem are simple. When federally funded research is conducted in universities, two kinds of costs are incurred: first, direct costs—those identified solely with a specific project, such as the salary of a technician, purchase of a specialized instrument, or travel costs; second, indirect costs—costs incurred in connection with a number of projects, programs, or activities but not identified solely with any one of them. Examples include heating, lighting, air conditioning, janitorial services, building and grounds maintenance, accounting, grant and contract administration, and libraries. As the General Accounting Office has stated: "Indirect costs are those that have been incurred for common or joint purposes of research, instruction, or related activity. Indirect costs are real costs of common or joint functions."[61] The major sources of indirect costs in 1975 include: departmental administration (31 percent), operation and maintenance (26 percent), and general administration (19 percent). The minor sources include: use charges for buildings and equipment (10 percent), research administration (6 percent), library costs (6 percent), and student services (2 percent).[62]

Since indirect costs cannot be charged directly to a specific project, they are typically allocated over all the benefiting projects in proportion to the relative total direct cost, the direct labor cost, or some other measure. For example, heating costs for all space used in grant and contract research are reimbursed through the operations and maintenance component of the indirect cost rate, rather than through charging a project specifically for the heating costs it used. Clearly, the distribution of indirect costs by individual projects cannot be an exact process, even though the indirect costs are as real as the direct costs.

Basic Policy Disagreements

There is no firm understanding among all parties concerned about whether the federal government should pay full indirect costs. The universities point out that they simply do not have the resources to pay for the heavy indirect costs generated by research, and that if the govern-

ment wants the work done it should pay the full price. They argue that the government would never think of asking private industry to absorb indirect costs, and that universities, as nonprofit institutions, should not be treated less favorably than profit-making concerns. The federal agencies, as well as some faculty members and administrators, often contend that a major reason for the existence of universities is to conduct research, and that therefore the schools should pay part of the cost.[63] So long as this basic disagreement exists, overt or submerged, it will be difficult to arrive at a stable policy.

In addition, the government and the universities find it difficult to agree upon the kinds of costs that are properly considered indirect. For example, in 1976 the Department of Health, Education, and Welfare proposed that no library costs should be included. But universities insist that libraries are needed for research and that therefore the cost of operating them should be allowed as an indirect cost. HEW later relented on this point. However, an area of disagreement still exists over the extent to which investigators actually use libraries—particularly the central library—and, accordingly, over the portion of library costs that should be allocated to research. With indirect cost payments approaching one third of all federal research funds expended by universities and with the absolute volume of indirect cost payments to universities exceeding half a billion dollars per year, the close attention of faculty, university administrators, federal administrators, and federal and state legislators is guaranteed.

The fact that indirect cost rates are increasing more rapidly than direct costs exacerbates the already existing differences. Indirect costs rose from $468 million or 28 percent of total university R&D costs in 1970 to $625 million or 31 percent in 1974.[64] Although indirect cost rates vary somewhat among federal programs, they all show the same rising trend. For example, the indirect cost rate for the NSF basic research project grants (indirect costs as a percent of total costs) rose from 16 percent in 1966 to 22 percent in 1970. In 1975, the rate reached 25 percent.

Faculty members and congressmen sometimes voice a similar grievance over the increase in the indirect cost rate, namely, that administrators deliberately boost the amounts. The heavy auditing of indirect costs, however, makes it impossible for universities to recover costs that either are not actually incurred or are not related to the research effort. In fact, the increase in indirect cost rates came about for one basic reason—the kinds of costs commonly designated as indirect have been rising more rapidly than those commonly designated as direct. Virtually all of the escalating costs generated by new federal legislation and regulations (equal employment opportunity, affirmative action, nondiscrimination by age, occupational health and safety, minimum wage, fair labor standards, unemployment insurance, social security,

and environmental protection) fall into the indirect cost category.[85] The cost of supplies and materials, equipment, books and periodicals, and particularly utilities, which enter into computing indirect cost rates, are rising faster than the wages and salaries that form the bulk of direct costs.

Decisions on the rules for and administration of indirect cost recovery affect a great many aspects of research policy, including the size of federal research appropriations, the number of grants that federal program managers can make, the financial stability of universities, and the distribution of power within universities. Thus it is important to take a closer look at the conflicting interests, in particular the disagreements between faculty and university administrators. Faculty and central administrators frequently take opposing views on such basic questions as: Are the costs real, or is the university making a "profit" on research? Should indirect cost receipts be distributed to the investigators whose grants generate the indirect cost funds or be disbursed centrally for general purposes?

A high proportion of principal investigators in both public and private universities believe strongly that since their initiative and ability brought funds to the university, they should be allowed to spend part or all of the recovered indirect costs for research support. Many are convinced that the indirect costs recovered in connection with their grants exceed those generated by their research; indeed, this is often the case, because indirect costs are generally an average of total indirect costs university-wide. Thus faculty view the payments as an inequitable diversion of researchers' funds from research to central administration. The chairman of the mathematics department at a prominent midwestern public university expressed this standard complaint: "The irritation between faculty and administration is moderately intense. Overhead irritates me no end. It provides absolutely no tangible benefits. A portion should be returned to us." A variation on the theme maintains that the creation of a slush fund for central administrators through indirect cost recovery takes money away from research. As the chairman of the botany department at a western public university noted: "This department does not get enough money back from overhead. A million dollars goes to the president from overhead and acts as a kind of slush fund. Overhead recovery in fact is not used to cover real actual costs." And the chairman of the department of chemistry at a first-rank private university: "We have no trouble maintaining our level of research funding, but we are squeezed as the university increases its indirect cost rate." An assistant professor of chemistry at another prominent private university highlighted an additional point—that increases in the indirect cost rate bore no reasonable relationship to any cost increases related to his department's research effort: "The overhead rate

jumped last year from 47 percent to 54 percent of everything except equipment. I see no reason for the increase and I resent having to pay for everything. This university looks on research just as a way of making money. The grants for science are in fact supporting the sociology department."

Many university scientists view themselves as adversely affected by the worsening financial position of universities, which forces them to try to recover full indirect cost. The head of the physics department at a prominent private university expressed this widely held point of view: "As the university's financial situation has worsened administrators have been forced to 'sharpen their pencils' to recover more in indirect costs. The increased recovery of indirect costs has meant fewer dollars for direct research costs. In this way, the general financial situation of the university has hurt the physics department both by reducing support services and by reducing direct research funds available due to the increase in indirect cost recovery. The investigators bear the brunt of the general institutional strains which have forced the university to try to recover more fully all indirect costs."

Resentment on the part of the principal investigators over various aspects of indirect costs is widespread. An adversary atmosphere pervades even some small private universities where faculty/administration relations traditionally have been very close. There is no single or simple solution to the deteriorating faculty/administration relations. Some of the resentment is a reflection of the generally poor relations at a particular institution. Some arises from cupidity and the unwillingness of faculty to recognize that they are part of the institution as a whole, and one that is costly to operate. Finally, a significant resentment is generated by the failure of central administrators to invest the time and effort required to educate faculty. But even improved communication is unlikely to resolve the conflicts fully. The contrasting perspectives are so intense that universities may need to develop more refined accounting systems to attribute costs more precisely to different units. Moreover, the federal agencies press, often with sound reason, for more precise cost accounting. One effect of such refinements may be to extend the practice of assigning different indirect cost rates to broad academic areas with substantially different cost structures. This prospect is viewed with apprehension in the universities since it would focus attention on potentially serious internal conflicts.

The perspective of university administrators often differs sharply from faculty attitudes. In a large university, where indirect cost receipts amount to millions of dollars per year, administrators see no other source than indirect cost payments to meet the high costs of research services.[66] Any change that would reduce the amounts recovered would throw an additional load on university budgets that already are

either showing deficits or are balanced by reason of stringent economies. The only way to adjust to reductions in the amount of indirect cost recovery would be to cut expenditures—maintenance, administrative costs, salaries, or research services—or to increase income—state appropriations, tuition, endowment income, or gifts. A sharp reduction in indirect cost recovery would generate a severe financial crisis in most large research universities and would have the most severe impact on those most heavily dependent on federal research funds.

Representatives of the central administrations uniformly take the position that indirect cost recovery is determined by uniform rules set by the federal agencies, under which less than full allowable costs are recovered. (While this is true, the form in which indirect costs are recovered may provide central administrations with one of their few sources of discretionary funds.) Administrators view the recovery of indirect costs as a university-wide matter and concede that the actual indirect costs incurred by specific research projects may be either higher or lower than the university-wide indirect-cost recovery rate. The vice president of a large private university summed up the prevailing attitude of administrators: "The situation is analogous to that of families with and without school age children who pay local taxes at identical rates."

The reactions of university presidents to typical faculty attitudes range from resignation to frustration. The comment of the president of a large eastern public university is characteristic: "I have done my best time and time again to explain how costly it is to provide the services that faculty members generally take for granted. We have to heat the buildings, and the cost of oil has tripled. A while back I got so irritated that I told a faculty member that he ought to take his NIH grant home with him and see how far he could get without the services provided by the university."

Indirect Costs and the States

Indirect cost recovery on federal research grants is a significant factor in the financing of major state universities and a far from negligible factor in state budgets. The states, of course, finance a portion of the general operating costs of public universities. Some of these costs fall into the category of indirect research costs. When the federal government reimburses universities for these indirect costs, it may be covering costs already met by the states. Accordingly, the states logically could request that the total applicable indirect costs be turned over to them. Actual practices vary widely. Many states permit universities to keep all or part of the federal indirect cost reimbursement, thereby in effect augmenting university budgets. Other states subtract the indi-

rect cost recovery from the regular state appropriation. Practices are so diverse and so complex that no short characterization is possible.

How a state treats indirect costs can be a decisive factor for the research-intensive university. If the state allows the university to retain some portion of the indirect costs recovered, these funds become discretionary money that can be used for scientific equipment, grants to young faculty, and various other purposes supportive of the research effort. If a state insists that all such funds be returned to the state treasury, thus becoming subject to the normal appropriation process, the likelihood is that a portion, perhaps a large share, will not be reappropriated for the support of research at the state's research-intensive campuses. Although no clear pattern of state reactions was discernible in our site visits, in nearly every state, legislative committees, coordinating bodies, and educational agencies were intensely scrutinizing the indirect cost issue. From this it can be assumed that universities will increasingly have to justify any practice that appears to evade normal appropriation procedures.

The Need for Improved Administration

Since all the parties involved have had difficulties with the administration of indirect costs, there is clearly a need to improve both administrative procedures and the degree of understanding among all parties involved—federal administrators at various levels, university officials, faculty members, legislators, and the attentive public. Universities have been partly responsible for the difficulties, particularly in cases where they have not administered indirect costs according to the federal rules. The Department of Health, Education, and Welfare has found other related abuses, such as counting student aid as salaries and wages to be recovered as grant costs, certifying the distribution of time and effort by persons unacquainted with the work of the faculty member, and transferring costs from one grant to another long after the costs were incurred in order to avoid cost overruns and to use up remaining fund balances. The extent of these improper practices is not known, but they occur frequently enough to warrant careful attention by universities.

Federal agencies have also been deficient as administrators of indirect costs. Because they have not always been staffed with those who understand the academic environment, arguments have occurred over such questions as, How frequently and precisely should faculty members whose salaries are paid partly from research grants report on how they spend their time? Differences over indirect costs within federal agencies have often been substantial, with program officers seeking to

hold rates down and sometimes even bargaining with faculty members to reduce requests for indirect cost reimbursements. Other officials with more general responsibilities are concerned with the basic relationships between the federal government and universities. They pursue a policy of full recovery and are more interested in the health of the institutions. In the absence of clear policy guidelines from high-level officials, administrators at lower levels sometimes make up their own changeable and often inconsistent policies.

Congress tends at times to view indirect costs as a form of profit to universities and an unnecessary expenditure. The Subcommittee on Labor, Health, Education, and Welfare of the House Committee on Appropriations has also looked askance at university administrative practices. As a report to the Subcommittee once noted:

> Many of them resorted to "gamesmanship" by reclassifying as direct costs certain activities which might normally be included in overhead, such as utilities, maintenance, depreciation and the like; the grantee was able to recover a substantial proportion of its expenses as direct expenses.[67]

This indicates how confusing the arguments over indirect costs can become. There is, in fact, no reason why given costs cannot be classified as either direct or indirect. As the General Accounting Office has pointed out:

> Whether a cost is direct or indirect is largely determined by the manner in which the institutions are organized and by the manner in which research is conducted. The same kinds of costs are properly treated as direct costs in some circumstances and as indirect costs in others.[68]

One significant improvement could result from a change in what might appear to be a minor detail in the administration of indirect costs. NSF requires that budgets prepared by individual investigators show indirect costs. This practice accentuates for the investigator and for review groups the fact that a specific amount for indirect costs is paid in connection with the grant, and it often leads program officers to negotiate a reduction in indirect cost payments with principal investigators. The NSF procedure is defended on the ground that reviewers should know the full cost of the projects they review (presumably indirect costs can thus be kept down). However, this advantage is far outweighed by the tensions it generates within universities by the bargaining over the indirect cost payments. The current procedure used by NSF and most other R&D sponsoring agencies pits the investigator against university administrators, and the program officer against the contract administrators in the agency.

Another procedure, adopted by the National Institutes of Health, reduces such tensions by allowing the principal investigator and reviewers to submit only direct cost budgets. Indirect costs are negotiated directly between appropriate administrative officials from the agency and the university. The increases in NSF indirect costs, as noted earlier, also appear to argue against the notion that the reviewers' advance knowledge of full costs will tend to keep indirect costs down. The increased tensions observable between faculty and university administrations could potentially be reduced by removing this source of friction.

Coordinating State and Federal Policies

A special complexity in government/university relations, especially in the case of public universities, stems from the frequently conflicting objectives of the states and the federal government. The kind of problems that have developed were suggested in the discussion of indirect costs. Inconsistent state treatment of indirect costs, or changes in the ways a state has previously viewed them, can greatly complicate the task of university officials and federal auditors. Many states have strong incentives to let the federal government pay all costs, direct and indirect, of research, whereas federal agencies are often inclined to push off onto state governments many research costs related to general maintenance of buildings and supporting services used in both teaching and research. A vice president of a large public university expressed the dilemma that is common to many state universities:

> We are really stuck. I have advocated for a long time that we go to the state and simply say that the unrecovered indirect costs from federal grants, which run maybe $3 million or $4 million over the biennium, are sort of a "finder's fee" for the huge amount of federal grant money we pull in. My colleagues say, "Christ, no, we can't do that! The state will ask us to identify what part of our budget is covering those costs and will cut that amount out of the budget." We have to argue to the state legislature that our general appropriation is all for teaching, and then the feds tell us that we have admitted our costs are mainly teaching costs and we're not entitled to recover more indirect costs.

Universities have increasingly been caught in the middle and have made contradictory arguments to state and federal officials. As state scrutiny of university programs increases, the possibilities for conflicts of this sort will likely grow.

STATE/UNIVERSITY RELATIONS

Difficulties in the relationships with state governments, particularly with regard to the public universities, go beyond indirect costs or other conflicts between state and federal policy. At issue are fundamental assumptions about the nature of the university, the proper scope of public support for higher education, and underlying trends affecting the fiscal capacities of state governments. This is not the place for a full review of the political economy of state government in the U.S., but a few observations are in order to set the stage.

In the industrialized states, which contain most of the large urban centers, the state government functions as a "bank" of first recourse for its constituent cities and urban counties. That is, the state serves as an alternative tax base of sufficient breadth to capture the revenue potential of metropolitan areas and harness it to urban social problems. In most of the large states, there is intense budgetary competition between the state's own operating functions and its role as a financier for localities, school districts, and special districts. The public university system in a large industrialized state is usually one of the three largest areas of direct state operation (the other two being mental hospitals and highway construction and maintenance). The largest categories of state aid to localities, including aid to elementary and secondary education, tend to be governed by some type of formula related to population, level of need, or some combination of these and other variables. These formulas are typically highly resistant to change because strong local constituencies defend them in the state political system. Thus it is often easier for a state to make reductions in its own operations—even if these must be larger percentage reductions in order to obtain the same fiscal effects—than to reduce aid to localities allocated on a formula basis. The university, as part of a shrinking proportion of the state budget that is subject to direct control by state authorities, may be an attractive target for cuts when cyclical or other budgetary pressures arise.

In many less industrialized states, the function of the public university tends to be seen as undergraduate teaching or vocational training rather than a commitment to research excellence. There are exceptions, however, and some of the less populous, less industrialized states have taken great pride in the research capacities of their public university systems. Also, many less industrialized states are characterized by a generally lower level of per-capita investment in government; in such instances, the university seems to encounter less intense competition for state funds from organized groups demanding state aid for local government services. Therefore, no clear pattern emerges with respect to how much the universities have apparently suffered in the recent contraction of state expenditures. (There was a massive change in the rate of expansion of overall state spending beginning in 1972: The ag-

gregate annual increase for total state spending in the U.S. dropped from more than 4 percent to under 1 percent almost overnight.)[69]

In certain instances the universities in smaller states were better able to maintain and improve their financial situations than were the universities in the large states characterized by intense budgetary competition, high levels of government services, and substantial financial interaction between state and local governments. Some states, especially food and energy states, have enjoyed spectacular prosperity despite the hard times elsewhere. The special complexities of the higher educational system in a particular state—the number and size of two-year and four-year colleges, technical and other universities, idiosyncrasies in the mode of governance, etc.—also influence the position of the university.

In both the large and small states, many of the universities' difficulties with state governments arise from the inability of university officials to articulate the likely effects of budget cutbacks on the quality of services or to present convincing arguments about the productivity of various levels of state investment in higher education. And state officials have begun to press universities for the evidence they need to assess the relative value of higher education spending as against that in other kinds of education or in other programs.

Sharp enrollment declines have a psychological effect on state legislatures that greatly complicates the university's task in presenting its needs to the state. The combination in some states of falling graduate enrollments, substantial construction in both public and private institutions in the previous decade, a sharply falling birthrate, and an oversupply of college-trained teachers has meant that attitudes toward the needs of higher education were bound to undergo some transformation. Unfortunately, in the days of rapid enrollment growth many universities used simplistic arguments based on student numbers to justify expansion in staff and facilities. State legislators and budget officials in turn have often fixed upon simplistic measures in weighing the effect of proposed budget cuts.

There does exist a vague understanding that the job description of a university faculty member includes more than the role as teacher, but state legislators have seldom had occasion to deal with issues of research support explicitly. Rather, they treat research largely as a residual matter, basing their decisions mainly on teaching requirements. Even legislators who are thoroughly familiar with the details of university finance—and frequently the ambitious legislator may choose to specialize in this area since higher education looms large in state budgets—often have not explicitly considered research needs and have never fully grasped the relationship between research and teaching. The various parties collaborated effectively as long as the general climate was expansionary and hard questions were avoided; but state/university relations grow more troubled as changing economic conditions

bring out latent conflicts and force states to make difficult decisions on priorities for public expenditures.

In some areas, such as agriculture and medical research, universities benefit from special constituencies that seek to protect research appropriations. In almost all other areas of research, the more typical arguments stress that the university cannot attract or keep well-known professors unless it provides substantial time and equipment for research. As university salaries have risen and the job market for college teachers has shrunk dramatically, these arguments have lost considerable force. Even when state officials appreciate the importance of university research to the nation as a whole, they tend to see the matter as a federal responsibility. At a time when universities are looking for ways to sustain their research efforts, the states are growing wary of assuming any new commitments to higher education and particularly want to avoid using state funds for matters they think should rest with the federal government.

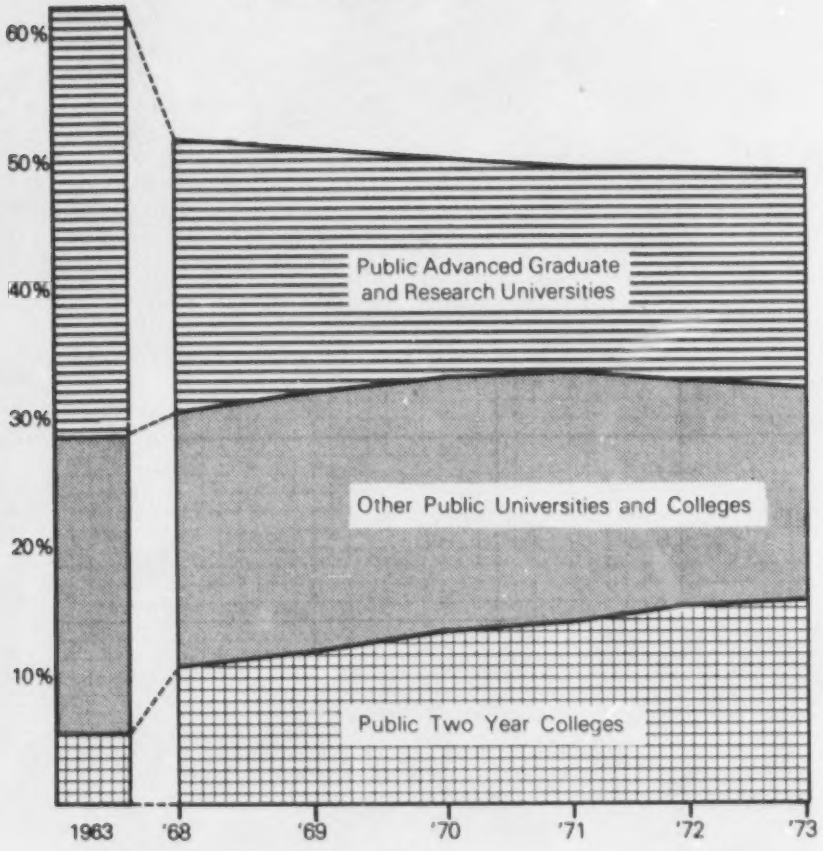
That political forces in the states have been shifting was confirmed during our site visits to public universities in 15 states. It is clear that the political support in many states for the research-intensive universities tends to be more fragile than that for many other educational interests. The research-intensive university is inescapably elitist in character and many state-wide coordinating bodies have become the vehicles by which various interests have sought to redirect resources away from elite institutions toward educational programs with wider popular appeal.[70] The coordinating bodies have begun to review state higher education policies, sometimes with a goal of equalizing per-pupil expenditures in all state institutions. At the least, they have initiated extensive data-gathering activities and sought to formulate plans for the entire higher education sector (including the private institutions).

The share of state resources going to the research-intensive public universities has decreased over the past decade, as shown in Figure 2. This trend can be seen as a natural result of the recent expansion of two-year and four-year colleges from a relatively small base. Yet the direction of the change very likely reflects further trouble ahead for the research universities. An important question will be whether the proportion of state education resources going to research universities will stabilize or whether the relative funding increase of the two-year and four-year colleges will continue. A related question concerns the degree of state support higher education can expect compared to that for elementary and secondary education. Until recently, the higher education community "neither needed nor developed as much political leverage as the elementary-secondary level....political strength has been diffused among institutions, academic and professional programs, and outside interests, with many lines of cleavage among them."[71]

It is difficult to obtain an accurate picture of what has happened with

Figure 2

Total State Appropriations for Public Institutional Types as a Percentage of Total State Appropriations for Public Institutions of Higher Education, 1963-1973



Source: Lyman A. Glenny and James R. Kidder, *State Tax Support of Higher Education: Revenue Appropriation Trends and Patterns, 1963-1973* (Berkeley, California: Center for Research and Development in Higher Education, University of California, December 1973), p. 21.

educational expenditures since the sharp reduction in overall state spending that began in 1972; not enough has been published about the recent period to allow a confident assessment. It does appear, however, that the share of state expenditures from state-generated revenues allocated to all types of education rose by 2.8 percent from 1966 to 1974. (This average hides extremes ranging from a 13 percent increase in Massachusetts to an 8 percent decrease in New York.) The expansion

has been achieved largely at the expense of other state-run operations, such as hospitals and highway construction. From 1972 to 1976, overall education expenditures—buoyed by a hard-to-reduce formula of support for elementary and secondary education—have not suffered the sharp retrenchments that have affected other state spending. In some states, the higher education share appears to have been reduced. However, not enough is yet known about the 1972-76 period to justify firm conclusions about expenditure trends.

The growth of state coordinating bodies has meant heavy administrative burdens for the universities. Studies of costs, enrollments, projected programs, and numerous other matters now must be exhaustively reviewed by institutions, often leading to increased clerical and administrative staffs. Much of the information requested by states is duplicated in federal data requests, but from a slightly different vantage point. The state and federal agencies may have markedly different uses for the same data, and data gathered for a state purpose can complicate negotiations on unrelated matters with federal officials. A graduate dean's comments illustrate the problem:

> The state had been on our backs. They thought we weren't doing much teaching and were getting big salaries. We sent out a questionnaire to the faculty trying to determine their average workweeks. The results showed that people were working long 50- to 60-hour weeks and we thought that this would satisfy the state. But then it hit the fan. Federal auditors got hold of the report and demanded to know why our computations on faculty time devoted to research projects were based on the assumption of a 40-hour workweek. It was a godawful mess. On all our federal grants now we report only percentages of total faculty time and we never define what "total faculty time" is.

Even where there is a broad base of state support for the university system, serious problems can complicate the administration of research. One important matter might be called "routine" budget management. As states have adopted progressive revenue systems—41 states now have income taxes—the vicissitudes in state tax intake have grown. The tax system is more sensitive to general cyclical trends in the economy, producing substantial revenues in periods of economic upsurge but sharp declines in periods of economic slowdown. Tax systems built around property levies produce more stable revenues but at lower levels. Since all states have constitutional limitations on borrowing capacities and deficit financing, state budgets usually have to be cut when deficits seem imminent. Educational budgets are "controllable" expenditures and hence often attractive candidates for these cuts. For the state budget official or legislator, money appropriated under the label "research" (as distinguished from the portion of faculty salaries that supports research) may seem a particularly likely candidate.

Few argue that budgetary crises should precipitate major cuts in instructional personnel. However, equipment, facilities, support staff, and overhead elements attributable to research are vulnerable. So, to some degree, are the projects requiring state matching contributions. The result is that budget crises tend to produce grave imbalances between the components of a research program, as well as absolute cuts in the entire program.

Public universities with substantial endowments are obviously better equipped to deal with fluctuations in state appropriations. A large volume of federal research funds can also be an asset, but these funds cannot be diverted to instructional or other uses not intended by the terms of a grant or contract. Moreover, it is difficult to increase suddenly the absolute levels of federal research funds or to alter the purposes for which existing funds were sought in order to compensate for reductions in technical personnel, graduate fellowships and teaching assistantships, supply budgets, library acquisitions, and other state-supported services—all of which affect, and limit, the university's ability to conduct research and to discharge its obligations under federal grants. The university becomes caught in something of the spiral that affects local government: More federal money is the solution to deficits. But, as an infusion of federal support relieves one problem, a further dependency is created and the university becomes more vulnerable to potential federal cutbacks or policy shifts. The university may seek additional federal research support to maintain its programs and may even be successful for a time. But higher levels of support are likely to result in additional costs that must be borne by the state. Achieving a new equilibrium in the face of federal or state cuts becomes progressively difficult.

Another point of conflict, especially between the federal government and the universities (but also between the states and the universities) concerns the freedom of faculty members to engage in income-earning activities (primarily consulting or research) while holding full-time university appointments. On most campuses this is an issue of great sensitivity that few administrators care to confront. Federal auditors, however, have recently questioned the fact that researchers are occasionally paid both through a federal grant to the university and through consultant payrolls associated with federally financed projects in the private sector. Federal officials do not insist that outside activity be banned; but they do insist that the university at least follow the same rules for federally financed activity as for other forms of outside activity.

When the question arises, usually in the context of startling information on payments to individual professors, the university is forced to state its policy with respect to outside earnings. Often it has no clear policy. Does "one day a week" mean one day in seven or one in five? Almost invariably the university does not have a mechanism for regular faculty reporting of outside income earned during the academic year.

Indeed, most do not have a definition of what represents "outside" activity, as distinguished from normal duties or from involvements that are directly associated with or beneficial to teaching or research functions. As with the issue of indirect costs, these questions bring up matters of fundamental importance for the university—the reality of the 5-day, 40-hour workweek; the minimum obligations of the faculty member to the university; the great differences in circumstances between the humanities, the sciences, and the professional schools; and the actual level of earnings expectations necessary to attract and hold people of the highest quality. As they are forced to sort out their policies in a context of internal pressures and outside criticism, universities will probably adopt more stringent restrictions on outside activities than are presently in effect. Unfortunately, such an outcome appears unlikely to contribute to more or higher quality university research.

Beyond specific problems, the underlying attitudes of suspicion and distrust that exist complicate the task of resolving disagreements. In the case of state officials, the fundamental concern is that universities have frequently seemed unable or unwilling to weigh priorities, and they have been reluctant to face the hard realities that to the state budget officials seem inescapable. University officials, on the other hand, often visualize state officials as insensitive accountants who lack an understanding of the university's special needs. This sharp divergence in outlook is bound to cause growing frustrations unless serious efforts are made to achieve better definitions of common problems.

The issues raised by the federal/state partnership in supporting university research have scarcely begun to be recognized and, when recognized, only rarely faced. The period of rapid growth in federal support of academic research concealed many of the important underlying issues: Is research principally a "national" need and therefore one that should be fully supported by the federal government? Should states provide basic support to universities only according to undergraduate enrollment formulas and without regard to the balance and competence of university research efforts and advanced graduate programs in the sciences? Should states pay indirect costs to universities when they act as conduits for federal research funds in the civil technology sector? What should be the ground rules on the division of costs between the federal government and states for initial construction and for maintenance of facilities constructed for scientific research and teaching?

The Education Commission of the States has issued a set of useful guidelines on a broad approach to the role of the state in graduate education and the need to reconcile the various federal and state policies impinging on academic research.[72] The Commission's report is a promising beginning to what should be a thorough review of the issues by state legislatures, universities, state coordinating bodies and executive agencies, federal officials, and the attentive public. The evident impor-

tance of the states in the future of U.S. academic research is one of the most important findings of the site visits for this study. The state role seems likely to grow in importance—to a limited extent as a direct supporter of research but significantly as a resource in overall institutional support. The wealthy states clearly have different requirements than some poor states, and thought should be given to regional consortia arrangements in which several states might cooperate, either to support specific institutes and joint research centers or to provide some underlying institutional support for advanced training programs serving the entire region.

In any event, it is clear that the relationships among the states, the federal government, and the universities have entered a critical era. Mere calls for a "dialog" or for better understanding of the respective points of view are not adequate. There is a need to rethink fundamental principles and to arrive at fresh formulations of the university's responsibilities to society and of society's commitment to the scientific effort in the universities.[73] Much of the burden will rest with the universities themselves. To the disappointment of state governments, universities have so far failed to harness their scientific and intellectual resources to the social and economic problems of states and cities; in contrast to the achievements of agricultural and medical research, there have been no obvious contributions in adapting technology to other public purposes. More serious, perhaps, the universities—particularly the university systems, which often include whole galaxies of institutions united under a chancellor without a central executive staff—have seldom been able to produce analyses and recommendations that are sufficiently cogent and well documented to be useful to the officials who make the financial decisions.

In the absence of an effective university role in clarifying broad choices, the decision process tends to move away from those who are most familiar with the universities' needs toward state budget and management officials. The challenge to the universities is to find a way to focus attention on the overall relationship between teaching and research in the higher education system and on the importance of preserving certain kinds of research in certain institutions. Clear choices need to be presented at both the national and state levels and related to outcomes that affect the quality of people's lives. Failing this, budget realities will force a continued series of improvised, short-run adjustments that are unlikely to serve either the interests of the universities or those of state and federal governments.

CONCLUSIONS

The problems highlighted in the foregoing analysis—the decline of supporting resources for research, decreased opportunities for younger scientists, and deteriorating government/university relations—are complicated by the weakening financial base of the universities. This major underlying factor has to be dealt with as universities seek to maintain a vigorous scientific research effort. Defining the economic health of universities is, of course, an elusive and difficult task. Criteria are imperfect and continue to evolve.

In a 1971 report on the financial health of 41 colleges and universities for the Carnegie Commission on Higher Education and the Ford Foundation, Earl F. Cheit wrote: "The essence of the problem is that costs and income are both rising, but costs are rising at a steady or a slowly growing rate, depending on the period and the measure used, whereas income is growing at a declining rate."[74] Two years later, Cheit found that most of the 41 institutions "seem to have achieved a tentatively stabilized financial situation. That stability is fragile, for it is the product of unusual cuts in expenditure growth and is based in part on favorable assumptions about external conditions—inflation, enrollments, private support, and public policy at state and federal levels."[75] In 1975, a study by the American Council on Education concluded that "progressive deterioration" has recently characterized the financial health of higher education and that "the process of decline appears to have accelerated during the past three years under the joint influence of inflation and recession"; the study found "massive evidence of widespread retrenchment in higher education."[76]

In large part, broad economic trends rather than specific government action have deepened the financial problems of the universities. The unusual economic conditions of simultaneous inflation and recession have, of course, affected all segments of society, but universities, as labor-intensive institutions, have been particularly vulnerable and have found few ways to pass on the costs to their consumers. For the private universities, costs increase each year slightly more than revenues, with the result that a gradual shrinkage in activities occurs. Because research, especially experimental research, has grown so expensive, administrators look to cuts in research services as economy measures. The public universities face an essentially similar situation as pressures on the states have forced more austere budgets.

The impact of these trends upon research efforts has not been uniform, as institutions have adjusted in various ways to tighter budgets. But the overall pressures tend to work in the same direction—toward reducing university services and support for research. Physical plant, maintenance work, and shop services are likely candidates for cuts. The small discretionary funds are also frequent, early casualties. As one

looks ahead, the pressures to curtail research services will likely mount, resulting in distortions in the research effort as well as overall reductions.

Although declining federal research support has not directly caused the financial woes of universities, dependence on federal funds for research has constituted a double-edged blessing. The dependence on federal research funds, which has increased dramatically among nearly all of the nation's major research universities, is a source of weakness and vulnerability even as it is a source of strength. The availability of federal support has increased dramatically, contributing to an expansion of research activities and a concomitant increase in related costs. Now dependent on federal funds, the private universities in particular have had to seek larger amounts of project support just to maintain existing levels of increasingly costly research activities. The universities have come to occupy a position similar to that of cities whose level of expenditures have increased as a result of federal matching programs. Even if the federal government guarantees nearly the full cost of research, the university incurs a higher level of expenditures than before. It is tempting to seek further federal support, which in turn leads to even greater dependence, along with increased vulnerability to changes in federal policy. And the universities, unlike the cities, are not governmental units with the ability to raise significant revenues on their own. The "federalization" of research, while undoubtedly a great boon to higher education, has created unusual dependencies with which the universities are ill-equipped to cope.[77]

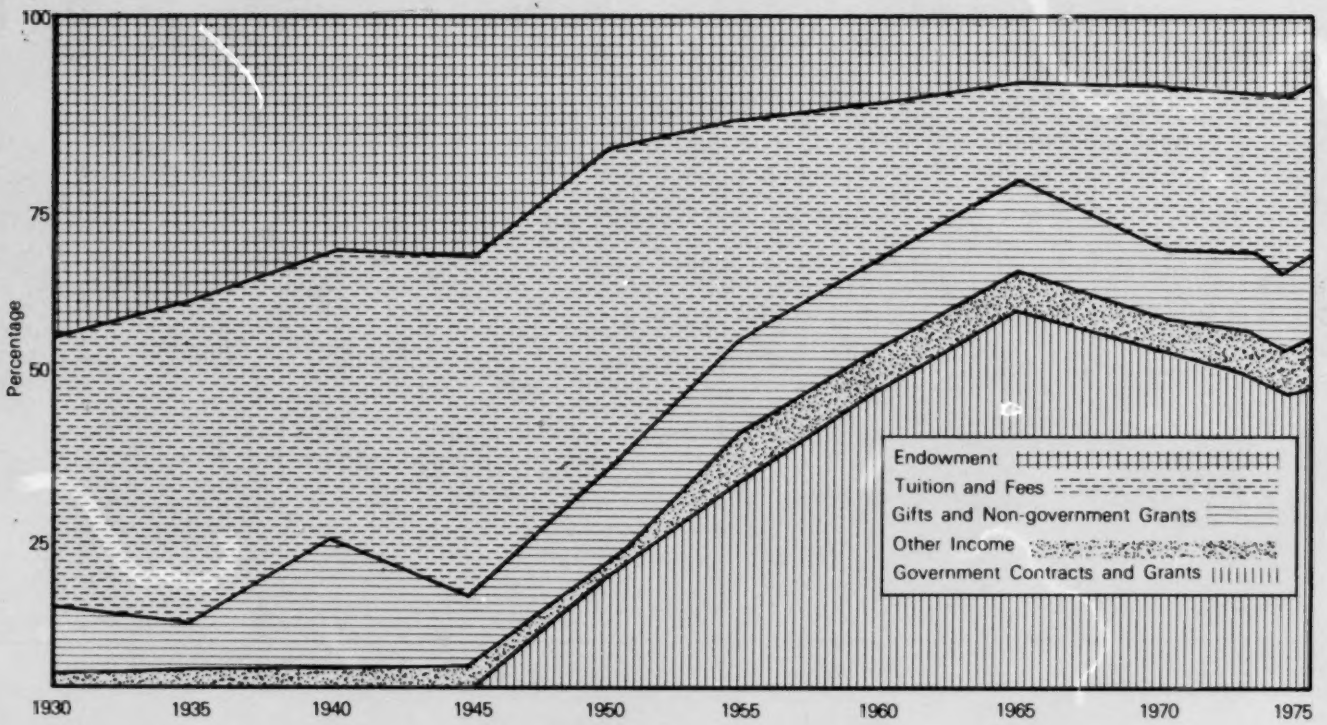
Figure 3 illustrates a typical pattern for private universities: a sharp increase in federal funding and the federal government's share of annual operating expenditures; a peak of federal support reached sometime in the late 1960s followed by a slight relative decline in the federal share of the annual operating budget. During the latter period, the university seeks to tap other sources in order to maintain the level of program effort and to achieve equilibrium. This pattern, though drawn from the experience of one school, is strikingly characteristic of the major private universities. The fight to stave off deficits is difficult and the question becomes, At what cost is a balanced budget achieved?

The science and engineering departments of strong private universities enjoy reputations for excellence and distinguished faculty that may carry them forward for a time, but their health is bound to be affected as supporting services erode, new appointments decline, and the university finds itself less able to fill in the gaps in programmatic support for specific projects.

The private universities' measure of dependence is shown by the following figures for 1974: Federally sponsored research funds constituted 39 percent of the general revenues for the year to Rockefeller University. The comparable figures for other institutions were: California Insti-

Figure 3

Consolidated Operating Expenditures for a Major Private University
by Source of Funds as a Percent of Total, 1930-1975



Source: Institutional Data

tute of Technology, 35 percent; Harvard University, 24 percent; Massachusetts Institute of Technology, 50 percent; Johns Hopkins University, 36 percent; Princeton University, 26 percent; Columbia University, 40 percent; Cornell University, 26 percent; and Stanford University, 40 percent.[78] Public universities are also highly dependent upon federal funds. "Dependence" may be present even when relatively small dollar amounts are involved. Several million dollars can sometimes exert a striking leverage on university affairs, greater even than the tens of millions produced by tuition or by a regular state appropriation.

What federal research support means to an institution, of course, varies substantially. For some, federal support provides the margin for excellence in scientific effort; for others, the margin for the existence of any science effort at all. But for all, the competitive pressures to maintain a substantial volume of sponsored research are intense, and fluctuations in funding cause minor to severe adjustment problems. How the institutional base might be protected by explicit policy action is a subject beyond the scope of this chapter or even this study. No single or simple solutions are available. Recognition of the full complexity of the problem must be followed by consideration of various alternatives. Full recovery of indirect costs, restoration of some institutional funding in addition to the dominant project form of research support, potential changes in tax laws to encourage more philanthropic giving, and strong action by the universities themselves to strengthen their financial management and priority-setting capacities—these are the kinds of actions that could ease the financial burdens as universities struggle to fulfill their role as a major performer of R&D.

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16. *Voluntary Support, 1974-75*, Ibid., p. 62.

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1974, op. cit., Tables B-9, B-10, p. 24.

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37. "Self-Supported Science Students Increased by 22 Percent in 1975," *Sciences Resources Studies Highlights* (Washington, D.C.: National Science Foundation, September 30, 1976), NSF 76-320, p. 2. One interesting development was the increase in part-time students from 23 percent in 1971 to almost 28 percent in 1975.

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54. Arthur B. Jebens and Earl Z. Irwin, *Environmental Health and Safety* (La Jolla: University of California Research Management Improvement Project, December 1974).

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57. HEW News Release, November 5, 1976. For an assessment of the earlier efforts by the Research and Development Board, see Don K. Price, *Government and Science* (New York: New York University Press, 1954).

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59. George R. LaNoue, "The Federal Tailors," *Education and Urban Society*, February 1977, Vol. 9. No. 2, p. 214.

60. For a full and competent definition of the issue, history of indirect cost payment, and discussion of the computation of indirect costs, see Raymond J. Woodrow, *Indirect*

Costs in Universities (Washington, D.C.: American Council on Education, March 1976), p. 87.

61. *Study of Indirect Cost of Federally Sponsored Research Primarily by Educational Institutions, A Report to the Congress by the Comptroller General of the United States*, Report 13-117219 (Washington, D.C.: U.S. General Accounting Office, June 12, 1969).

62. Department of Health, Education, and Welfare, Office of the Comptroller, January 12, 1976.

63. Universities sometimes agree that it is equitable to ask them to share a fraction of the cost of sponsored research, but if this is done they insist that government pay a fraction of the total cost of research and not pay full direct costs and a fraction of indirect costs.

64. *National Patterns of R&D Resources, 1953-1975*, p. 21 (NSF 75-307). Total federal R&D expenditures exclude federally funded research and development centers and R&D plant. Indirect cost figures compiled by the Division of Financial Management Standards and Procedures, Office of the Comptroller, Department of Health, Education, and Welfare. (It would be preferable to have a total expenditure figure derived from the same source as the indirect cost payments, but the figures are adequately precise.)

65. For an exploratory analysis of the financial impact of federal regulations on universities, see Carol Van Alstyne and Sharon F. Coldren, *The Costs of Implementing Federally Mandated Social Programs of Colleges and Universities* (Washington, D.C.: American Council on Education, 1976).

66. Some central administrations have decided not to collect the full indirect costs to which they are entitled. In one private university, the indirect cost rate was lowered by two points because the faculty objected to rising indirect cost rates. At another private university, the full allowable indirect costs are not claimed because of a judgment that this action puts the university in a better competitive position to secure research grants. Some state universities do not press for full indirect cost recovery because state governments claim part or all of indirect cost reimbursement. These variations only begin to suggest the differing practices among universities that help to make indirect cost recovery such a complicated issue.

67. Surveys and Investigations Staff of the House Committee on Appropriations, *Overhead Reimbursement to Grantees and Contractors*, A Report to the Committee on Appropriations, U.S. House of Representatives, March 1975 (Released by the Committee on February 12, 1976), p. 84.

68. *Study of Indirect Cost of Federally Sponsored Research*, General Accounting Office, op. cit., p. 17.

69. We are indebted to Professor Edward K. Hamilton, Graduate School of Business, Stanford University, for these figures and for his assistance in the preparation of this section of the study. Unless otherwise indicated, figures used in this section are derived from a background analysis prepared by Professor Hamilton.

70. The number of coordinating boards depends upon nuance of definition; most now exist under the authority of section 1202 of the Higher Education Amendments Act of 1972, but many of these are older bodies that have been redesignated as the state coordinating board under authority of the Act. For a list of coordinating boards, see "State-Wide Boards for Four-Year Colleges," *The Chronicle of Higher Education*, October 18, 1976, p. 13. For a thoughtful discussion and analysis of the role of the coordinating bodies, see Robert O. Berdahl, "Problems in Evaluating State-Wide Boards," in Robert O. Berdahl, ed., *Evaluating State-Wide Boards* (San Francisco: Jossey-Bass, 1975), pp. 1-13, and P.R. McConnell, "Coordinating Higher Education," *Higher Education Review*, Vol. 8, No. 1, Autumn 1975, pp. 45-57.

71. Michael D. Usdan, David W. Minar, and Emanual Hurwitz, *Education and State Politics* (New York: Teachers College Press, Columbia University, 1969), p. 172.

72. See Education Commission of the States, *The States and Graduate Education*, Report of the Task Force on Graduate Education (Denver: Education Commission of the States, February 1975) and Association of Graduate Schools, *The Research Doctorate in the United States*, Report of the Association of Graduate Schools to the Association of American Universities (Washington, D.C.: Association of Graduate Schools, 1976).

73. See Dael Wolfle's excellent paper, "The University's Compact With Society," in Bruce L.R. Smith, ed., *The New Political Economy* (New York: Halsted Press of John Wiley and Sons, 1975).

74. *The New Depression in Higher Education: A Study of Financial Conditions at 41 Colleges and Universities* (New York: McGraw-Hill, 1971), p. 137.

75. Earl F. Cheit, *The New Depression in Higher Education—Two Years Later*

(Berkeley: Carnegie Commission on Higher Education, 1973), p. 71.

76. Lyle H. Lanier and Charles J. Andersen, *A Study of the Financial Condition of Colleges and Universities: 1972-1975* (Washington, D.C.: American Council on Education, 1975), pp. 75, 77.

77. See William D. Carey, "A Question of Checks and Balances," *Science*, Vol. 194, No. 4271, December 17, 1976, p. 1233.

78. These figures are drawn from public annual reports issued by the universities. They are, of course, subject to numerous idiosyncrasies of definition and classification and should, therefore, be used with caution. Our judgment is, however, that these figures do not overstate, and may understate for some institutions, the degree of dependence upon federal research support. For a thoughtful assessment of the problem from an institution's perspective, see Gerard Piel, Chairman, *1975-76 Report of the Standing Committee on the Natural and Applied Sciences to the Board of Overseers*, Harvard University, September 21, 1976. In most institutions, the dependence on federal funds grew sharply until the late 1960s when it began to decline somewhat. The dependence on federal funds appears to be the greatest in the major research universities. For recent data on a sample of 46 universities, see Lyle Lanier and Ivars Zageris, *A Study of Financial and Educational Trends in Research Universities in Relation to Federal Funding of Health-Related Research: 1964-1974* (Washington, D.C.: American Council on Education, March 1976), Table 8, p. 23.

VI

Conclusions

The scale, vigor, and creativity of American science are outstanding but the signs of trouble for the future are unmistakable. Deterioration may well proceed long before the matter becomes a public issue, and a downward spiral, were it to develop, might be difficult to reverse. The trend toward concentrating the scientific effort among fewer research departments needs to be addressed. A somewhat more modest research establishment may be emerging, but the academic research effort must remain relatively pluralistic, broadly based, and competitive.

A changing relationship between graduate education and research has potentially far-reaching consequences for the universities, leading toward a weakening of the traditionally close link between teaching and research activities. The dramatically increased public concern and involvement in complex scientific debates has become an important element. The public, news media, state coordinating bodies, congressional committees, and other participants will share in important decisions on the future of university research. Changes in the traditional authority patterns within universities pose difficult choices. Prudent decisions now will preserve the long-term strength of American science and the academic research effort.

Chapter VI

Conclusions

This study has reviewed the experience and performance of academic science over the past decade. Our findings are cause for both satisfaction and considerable apprehension. On the positive side, the continued scale, vigor, and creativity of American science in virtually all fields of the research endeavor can be termed outstanding. For those concerned that the funding climate of the past decade might have resulted in a sharp setback for the nation's science effort, these findings will be reassuring. Contrary to some fears, there has been no general breakdown in morale among the nation's outstanding academic scientists. Furthermore, there exist signs of progress and improvement in the research environment. Collaboration between universities and industry, for instance, after a considerable period of arm's-length relationships, has begun to take root again. A deeper awareness of how interdependent the different types of R&D performers actually are has been created, along with more realistic expectations about the special capabilities of each. Calm has returned to campuses after the turbulence of the late 1960s, and the atmosphere necessary for serious intellectual endeavor has been largely restored.

Yet the signs of trouble for the future are unmistakable: The principal problems, discussed in earlier chapters, need not be detailed again. They relate to the underlying strength of the institutional base upon which the predominant system of project support must rest. The evidence of deterioration in the underlying infrastructure for science is now extensive: Facilities are becoming outdated; there are difficulties providing adequate maintenance for facilities; and less discretionary money is available for departments to "fill in the gaps" and tide investigators over periods of uncertain support for their work.

The problems facing academic science relate also to the deteriorating relations between the federal and state governments and the universities. The complexity of keeping the research effort going, absorbing as it does more resources and energy each year, begins to cut into the time necessary for creative scientific endeavor. The most serious aspect is that such adverse trends all seem to reinforce each other and point in the same direction: toward a less speculative science, taking fewer chances, sticking with established lines of investigation. The situation now seems the same for the established investigator, for the agency program official, and for the graduate student. "Playing it safe" becomes the path of least resistance. By no means have these attitudes become the norm among university scientists or program officials. But the trends appear to point in those directions; unless they are checked, the consequences for American science could be serious.

The academic science system has great momentum, and the near-term prospect is for continued excellence in the scientific effort. The problems appear further ahead. The total system of American scientific research operates on a time cycle considerably longer than the electoral rhythm of the political system or the attention span of the communications media. The nation cannot allow this resource—the scientific capability built up in the universities since World War II—to deteriorate without full recognition of the potential costs of public neglect of academic science until the signs of trouble have become manifest. This study is not meant to strike an alarm or sound an unjustified note of gloom. We do see, however, a possibility of a potentially serious decline in research capability before the problem emerges as a public issue. The same momentum in science that carries the system forward in times of fluctuations of support, temporary economic downturns, and relative austerity can also work in reverse: A downward spiral, if allowed to develop, could be difficult to turn around. In this event, a costly and massive public investment would be necessary to revive a faltering system. Yet attention to trouble spots now can maintain the healthy, dynamic state of a successfully functioning system.

This study proposes no laundry list of specific policy proposals. We have strong views about many issues, some of which were expressed in Chapter V, but it is more useful to focus attention on the most critical developments affecting the system of academic science as a whole after which many particular choices can be debated.

Academic science is undergoing changes, possibly even rapid changes, and thus it is important to look at alternative future lines of development. Three developments within the system of academic science seem to us particularly important:

- The stratification that appears to be emerging within the system, suggesting that fewer universities will be capable of conducting research of the very highest quality in the future;

- The changing relationship between graduate education and research in the nation's universities, leading toward a possible weakening of the close link between research and teaching activities; and
- Strains in the authority relationships within universities that could result in fundamental changes in their mode of governance.

Stratification

One of the major findings of this study is the negative impact of recent trends on the less distinguished science departments and less distinguished scientific investigators. By most measures—research funding, graduate student enrollments, or other indicators of the vitality of the research effort—the most serious impact of recent trends has been felt in second-rank departments and institutions. In contrast, the leading science departments have tended to retain their scientific eminence and their relative strength. They have even strengthened their positions somewhat given the difficult circumstances for contemporary higher education. The downward trend has not appeared uniformly throughout all second-rank institutions, and the indicators of trouble have not always reached an advanced state. But the signs are sufficiently clear to warrant the conclusion that a very rapid deterioration in the relative position of many weaker departments could well occur in the near future. To the extent that a somewhat austere funding environment for academic research continues, these tendencies toward stratification may accelerate. The realities of modern science—the cost and increasing complexity of experimental research at the frontiers of knowledge—also create strong pressures on the system to have fewer departments fully prepared to conduct research of the highest quality.

Is this a development the nation should view with alarm, or should we accept and encourage it? No doubt some of the adjustments that have taken place have been healthy for the overall system. PhD programs in the 1960s perhaps overexpanded, and some of the research undertaken a decade ago was of less than first-rank quality. It is of course extremely important that the highest quality science continue to be nurtured and protected in a period of relative austerity if the United States is to continue its scientific leadership. It is in one sense highly reassuring that our system of awarding research grants and contracts, based on competition according to scientific merit, appears to have achieved its aim in making certain that preeminent investigators are able to continue their work, and in most cases with adequate support.

But there is a legitimate concern that the erosion may have proceed-

ed too far and may indeed have left the nation with too few centers of scientific excellence. Since the nineteenth century the country has encouraged a broad base of scientific competence in many universities where research and teaching would be relatively closely related.[1] If the nation were to move too far in the direction of fewer and fewer outstanding university research departments, this national breadth and diversity would be endangered. It is possible that the competitive elements in the system could also be undermined if there were too few universities fully equipped for preeminent research. The nation might then be forced to rely on a narrow base of dominant centers. The competitive pressures in the system can, however, operate quite effectively with, say, 50 strong departments competing for research funds in a certain field in contrast to twice that number. But could such competitive pressures work equally well if there were only 15 serious producers of quality research in a given scientific field?

There are a variety of pressures pushing in the direction of increased stratification; these are related to the internal logic of a field, the practice of funding agencies to focus research energies on a specific target, the scale and cost of modern instrumentation and facilities, or other causes. They all pose these important issues: What kinds of research must be preserved as a matter of policy, and in which universities? Is it enough for the nation to have a relatively small number of clearly elite centers of scientific excellence?

There is little in our national experience to provide a ready basis for answering such questions. A return to a somewhat more stratified system of academic science would mean a partial return to the system prevailing before World War II, when relatively fewer universities were serious producers of research. But that was before the United States had become a leader in world science; American scientific preeminence occurred at a time when academic science was developing in a large number of new or revitalized universities all over the country.

Although the strongest departments and universities have remained in a relatively more secure position, signs of trouble are also appearing there. The weakening of other parts of the research network might gradually ripple through the entire system. There could be fewer opportunities for the most creative scientists to synthesize in their own theories the empirical work of others, less scientific activity at the periphery that feeds the mainstream of a discipline's development, and potentially fewer well trained and highly motivated students attracted to the main centers of scientific activity. Other undesirable side effects might result if too much divergence were allowed to develop among the science capacities of various universities.

Besides serving its unique role as an incubator for the next generation of scientists, the university is also engaged in the transmission of knowledge to the public. It could be highly undesirable if students in a

certain region of the country were cut off from exposure to the most creative thinking available. No doubt the cultural life of a community could suffer if its higher education institutions lacked a research capability. There are also questions of balance in the internal development of a discipline. A broad base of inquiry, with many investigators spread across the entire spectrum of a field, has traditionally been one of the strengths of American academic science. If the total effort were focused exclusively on the most exciting "cutting edges" of a field, some important links among disciplinary subfields or across disciplinary lines could very well be missed.

We call attention to these issues not because there is one clear and obvious path that the nation should choose; in fact, we see no such single path. We believe it important for public officials, university spokesmen, and scientists to confront these issues. They must analyze the consequences of choices for people's lives and for the long-term benefit of the nation as a whole. The decade ahead will be one of continuing and most likely accelerating change as universities begin to consider their future courses of development. On the basis of present trends, it seems likely that some smaller universities will essentially confine their science efforts to high quality teaching at the undergraduate and first professional degree levels. Others will concentrate on specialized research efforts that take advantage of their special strengths.

Among all universities there will probably be considerable experimentation with distinctive PhD programs and research efforts. The National Board on Graduate Education recently issued a strong call for such university efforts.[2] Based on our site visits, we believe that many universities are beginning to think seriously along the lines of specialized and differentiated graduate programs. A number of universities may decide that they cannot maintain coverage in depth across the entire range of modern science or staff every specialty within a discipline; they may instead concentrate their scientific research efforts in several departments or focus on certain subfields within a department. (This is somewhat analogous to the situation, as discussed by Gilpin, of a small country that must select only certain areas of scientific endeavor for special attention.[3]) Gross and Grambsch have summarized the beginnings of this trend toward a more diverse set of academic institutions and science departments:

> Universities have become distinctly more stratified. The sets of goals exhibiting congruence among universities show distinct differences and clusterings. Goals and goal preferences are found to divide sharply in private as compared to public universities, in highly productive as compared to less productive universities, and in top prestige as compared to bottom prestige universities. The stratification has reached the point where one might more appropriately speak of it as fragmentation, for stratification does imply that the universities are part of the same system. If anything, some universities (most strikingly those of

> low prestige) appear to be seeking wholly new objectives which do not compete with those of the more prestigious universities. This tendency suggests a breakup of the system itself, with still further options for students of different interests and talents. The university system may then become less of a monolith, better adapted to the enormously diversified student body that now finds attendance at an institution of higher learning not simply an advantage but an obligation.[4]

Despite the likelihood of significant changes in the next decade—some universities dropping research programs, fewer universities managing comprehensive coverage of all major science fields, more specialization in research and training programs, and the like—there are probably limits to how far these developments will extend. It does not seem likely to us that the country will encourage or permit a basic shift in the nature of its higher education system—one that would result in a dozen or so major research universities, the remainder acting essentially as teaching institutions. And it is equally unlikely that some two hundred strong, research-intensive, doctoral granting institutions will be preserved in the future. Something between the broadly diversified system of the present and an extremely narrowly based system will probably emerge for academic science.

What we see as the most appropriate alternative is a somewhat slimmed down but still broadly based and competitive system, with vigorous ongoing scientific activity in numerous universities across the country. Without entering into extended analyses, we are skeptical about any revival of the NSF Science Development Grants Programs tailored to "needy" or "emergent" departments or universities.[5] Similarly, proposals for special grants to selected "outstanding" departments or universities seem of doubtful feasibility and wisdom. Programs designed to aid special constituencies inevitably tend to introduce political considerations into the process of awarding research grants. These are at odds with the principle of competition on the basis of scientific merit—a principle that has served the country well. The dominant pattern of federal support for university research is, and should remain, the competitive award of project grants and contracts, as urged by the Bell Report over a decade ago.[6]

The preservation of competition based on merit does not necessarily lead to the conclusion, however, that project support alone—and no other form of assistance to the university research effort—can be justified. Forms of institutional support exist that do not conflict with the merit principle—indeed, they can be geared to a merit formula—and they could help keep financially troubled universities engaged in creative research. The NIH biomedical research formula grant is one such example: It assists universities, up to a certain ceiling, with flexible funds to meet needs not covered by direct project grants. These discretionary funds are based on the amount of total competitive project

funds received by the university. In the 1960s NSF had a formula grant similar to the NIH basic biomedical research grant, but it was recently phased out. The NSF formula was inversely related to the total amount of competitive grant funds received by the institution, which gave a slight proportional advantage to the smaller universities.

A revival of the NSF program, a strengthened NIH program, and the possible extension of this grant approach to other major federal R&D agencies could significantly assist universities in their efforts to retain a high-quality research capacity. Although this support formula would not persuade a university with little or no research capacity to compete for project funds, it would provide for those already committed to research a small amount of funds for equipment needs, start-up grants for young faculty, research assistants, or other special research purposes. The Bell Report, while endorsing the continuing framework of the project grant system, also recommended that a modest level of general institutional support be made part of the total federal effort.[7]

The readjustments that will take place over the next decade in the research activities and graduate programs of various universities will probably be determined by the intense competition among universities, and within universities, rather than by a central plan or design. Here again we express our view that these marketplace decisions are apt to be more rational than any vision of the role of academic science held by central planners. The nation will benefit from continued research competition; most of the changes in the position of universities will be associated with changes in the perceived quality of an institution's research programs. The decade ahead is likely to see even greater fluidity than in the recent past, with a number of institutions receiving more federal research funds while others drop back. Most of these adjustments will reflect some degree of logic inherent in the situation of a particular university, even though the decision to phase back an effort may be extremely painful and may foreclose the opportunity for a university to recover scientific strength in a field for years to come.

One uncertainty that complicates this competitive approach is the weakening financial base of many universities. The general financial difficulties faced by universities may present a situation where research competition between universities cannot operate effectively. A sharp deterioration in the total scientific capabilities of a wide range of universities could occur that would go beyond a healthy competitive adjustment in the system. Most universities now live in a state of manageable discomfort. None can fully do what it would like for its students, in research or in public service. Many suffer deterioration in their basic financial situations. All are apprehensive that restricted income and rising costs will further undermine their capacities to do adequately what society asks of them. A major factor influencing research in both public and private universities is the virtual disappearance of an

institution's own funds for direct support of research. Over the long run, research cannot continue to flourish in universities without institutional strength or organizational integrity.

Relative declines in faculty salaries, deterioration of physical plant, sharp restrictions on services and travel, inability to undertake risky innovations with university funds, starvation of library budgets—all could have powerfully depressing effects on academic science. Clearly, the significance of unrestricted research funds will be enhanced. Even small discretionary gifts and grants could become highly important. Any university with access to even moderate amounts of discretionary funds will now have a distinct advantage in attracting outstanding faculty, in entering new fields of investigation, in setting its own priorities independent of swings in federal priorities, in starting younger faculty on research careers, and in dealing with discontinuities inherent in the project system of support.

The federal government continues to view universities as it does other suppliers of research services, principally as sites where research of interest to federal agencies can be carried on. It does not recognize (except in the case of the health professional schools through the relatively small NIH formula grant linked to biomedical research) a national responsibility for the continuing health of the universities themselves. We believe that the current federal view is inadequate and that measures need to be devised to strengthen the institutional base of universities within the continuing framework of the competitive project grant system.

Because of their declining financial position and the need to retain a reasonable degree of flexibility, the universities will no doubt continue to press for federal support not tied to specific projects. This seems likely even though general institutional support, if achieved, would make universities even more dependent on the federal government and more vulnerable to changes in federal policy. There is no easy answer to the dependency problem: The "federalization" of academic research has brought with it financial burdens for the universities that can only be alleviated by new infusions of federal support—and in turn are made worse by them. The more general—i.e., flexible—the funds, the more valued they will be, and the more leverage over university affairs even small amounts of federal money will enable the government to have. For the foreseeable future, the fundamental difference between universities and the federal government on the issue of institutional support will probably remain unresolved.

Institutional funds may not, of course, basically alter the tendencies toward stratification in the university research system, but some formula-type funds could at least provide a modest amount of flexible support to those institutions that traditionally have lacked endowment income, fees, gifts, and other flexible monies. Unless an institution can

mount some degree of research effort, it will not be eligible for support under any formula pegged to the level of competitive grants received. The stratification issue clearly has roots in many developments of the past decade, and there is no ready answer to how the universities themselves, federal and state government, corporate and philanthropic leaders, and the public should react.

The trend toward fewer universities and departments able to mount first-class science efforts, especially in the experimental research areas, will continue so long as federal research support remains essentially level, which is likely to be the case. The most likely prospect for federal research support over the foreseeable future is that it will increase modestly, just matching the rate of economic growth. A return to the spectacular growth rates of the 1960s seems highly unlikely. To some extent universities may be able to preserve their research missions by achieving a greater functional division of labor among themselves and by developing highly specialized research programs. But there is a certain minimum coverage of basic science fields that a university must undertake in order to retain its research vitality. An overlap of function and competition for scarce research funds seems guaranteed by the realities of the academic science system. The task of analyzing the implications of these trends, and establishing the links between them and possible corrective action, should be high on the agenda of government officials and educational planners. The possibility of very rapid changes in the university science system in the years ahead makes a more comprehensive survey of academic science highly advisable. The new White House Office of Science and Technology Policy, as well as appropriate congressional committees and state legislative committees, would be logical sponsors of such analyses.

Graduate Education and Research

Related to the tendencies toward a smaller number of departments able to mount a first-class research effort in various fields is a second basic finding of this study: the changing relationship that is beginning to emerge between graduate education and research. This development carries potentially far-reaching implications for the universities, although uncertainties concerning student enrollments, career choices, and related matters make it difficult to assess precisely the problem. Past manpower projections, for example, have been notoriously inaccurate, and there is little reason to have more confidence in the current projections.

The decade of the sixties was characterized by the synergistic relationship between expanding academic science and the increases in gra-

duate enrollments, undergraduate enrollments, and faculty size. The expansion of graduate enrollments produced teaching assistants, without whom many universities—particularly the public ones—could not have fully met their undergraduate teaching obligations. The graduate student research assistants acquired skills as apprentice scientists, and the resulting PhDs in turn became the junior faculty required for the growing system. Although varying from field to field, the research output of faculty members was linked in part to the graduate students who participated in the research.

This mutually reinforcing set of conditions has now begun to break apart. Enrollments for advanced degrees in the physical sciences and some engineering fields have declined; for some universities this has already meant a reorientation of teaching efforts, often resulting in increased undergraduate teaching loads for senior faculty. (In other cases what has suffered, with reduced numbers of available graduate teaching assistants, has been the quality of undergraduate education.) The declines in graduate enrollments have posed problems of a complex and subtle nature for the research activities of many departments. We cannot provide a firm assessment of the impact of the enrollment declines on the university science effort to date nor predict what the likely future effects will be. But there is enough evidence to suggest that the nation will need to reassess its traditional assumptions about the relationship between research and graduate education. It is necessary to distinguish carefully among fields of science, for not every field has suffered sharp declines in graduate student enrollments or has reached the stage where high-cost instrumentation may in the future force research off campus. But the trends require serious examination.

If the trends observed in this study are found to characterize the higher education system generally, one would expect that, were they to continue, many PhD programs in the science fields would encounter serious trouble. A share of these would be terminated, suspended, or otherwise cease to be a reality. For the institutions and departments directly involved, choices would have to be made between continuing a research effort in the absence of graduate students (for example, by attempting to substitute research technicians, support personnel, or postdoctorates for graduate students) and deemphasizing research to concentrate on undergraduate or MA-level teaching. The research activities that have traditionally been carried on at distinguished liberal arts colleges provide a model that departments with a troubled graduate program might increasingly adopt. Realistically, however, the conduct of a significant research program is generally difficult in an atmosphere without a serious PhD program.

The initial consequences, some of which are already apparent, include these: diminished research activity in some departments; continuing research activity in other departments, but with a semi-institute model

using full-time technicians or support staff; the hiring of fewer new young faculty; low morale and disorientation among some members of a department; and an increasing separation of teaching faculty from research faculty. As a research unit becomes institutionalized, there is a tendency for it to grow apart from the regular teaching activities of the department and to develop an identity of its own. If it becomes a success, it can draw the most energetic faculty members away from teaching and toward a stronger psychological identification with the research institute.

Some evidence of such tendencies was observed in various site visits, but there was sufficient variation to make it impossible to identify any overall trend. For some departments, adjustments were made that simply altered slightly the teaching loads of faculty, but without visible short-term effects on research activity; for others, the impact appeared to be more substantial. For all departments with substantial enrollment declines, concerns for the long-term future were evident: Would the department shrink in size or be unable to promote younger scientists to tenure positions? What sort of research interests could the department develop that would not require graduate students? What was striking was the number of departments in the physical sciences that were beginning to discuss openly such concerns, usually triggered by persistent declines in graduate student enrollment, but also related to the increased cost of equipment, the difficulties of securing research funding, and other factors.

Most of the distinguished science departments were not yet facing pronounced enrollment declines, but they could begin to experience difficulties if graduate enrollments fell further. The major departments could experience a special problem in the future even if their graduate teaching programs remain secure. If there were fewer strong centers of scientific research in the universities, the scale and complexity of research efforts could grow to the point where the university would begin to resemble a national laboratory or FFRDC. Already many leading departments have developed a research career line independent of the regular teaching career ladder; the size of such staffs has grown considerably and they have developed "rolling tenure," i.e., a university commitment to maintain them for a certain period of time in the event of contract or grant termination. For practical purposes, such research staff will probably come to have tenure or a very close equivalent. These arrangements have the potential of creating more than routine management problems, even though few major difficulties so far are reported in most universities with this system.

But were such trends to accelerate, personnel hired outside the regular career ladder and lacking the same opportunity for careful peer evaluation could begin to change the character of the institution. The teaching and the research effort could grow further apart; research by

faculty identified with the department's teaching efforts might differ from the larger scale efforts of their colleagues affiliated with an institute within the university. Large-scale activities attract professional personnel of different levels of training, and the graduate student becomes only one part of a complex undertaking managed by a project director. The kind of educational experience available to graduate students in the context of a large project may not as readily develop the habits and traditions of an independent investigator as the traditional patterns of graduate education. The umbrella contracts in effect now in some physical science departments offer many advantages: support for graduate students, research funding for young faculty who might have difficulty securing it on their own, and the opportunity for rapid advances across a broad area of science. But if not properly administered, they also contain the potential for abuses: neglect of the training function, overdirection of young faculty and graduate student research interests, and undue attention to the most glamorous research areas and neglect of important subfields.

The large-scale effort is also likely to be the target of pressures for short-term results on urgent social concerns; thus an institute within a university could face the problems of developing a mission and becoming tied to that mission in the fashion of an FFRDC. The traditional advantages for the faculty member of a close link between graduate (and undergraduate) education and research—self-renewal, exposure to fresh ideas, new research opportunities, flexibility, and others—could be jeopardized. In any event, there are signs that the U.S. academic science system may face circumstances that would move it somewhat toward the pattern prevailing in other nations, such as West Germany and the U.S.S.R., where a looser relationship exists between the universities' educational and research functions. This nation needs to assess the implications of such a development—to decide whether society should welcome, encourage, seek to prevent, or modify the tendencies toward decoupling the research and graduate education functions.

Several aspects of this problem deserve particular attention. One is the need for guidelines to help decide the fate of PhD programs now experiencing difficulties, many of which were either created or expanded in the decade of the 1960s. Inevitably, some PhD programs will be (and should be) phased out during the next several years. This is a sensitive, complex process involving universities, state governments, and to a lesser degree (and only indirectly) the federal government. Where retrenchment is indicated, the criteria to be applied should include those developed by the New York State Education Department in its doctoral review program:

> • The quality (and accessibility) of the faculty and of the program of graduate instruction in each program, as they can be inferred from the opinion of other scholars in the field, the view of faculty members in

related disciplines at the institution, and any available evidence based on the opinions and experiences of graduate students.

- The number and quality of students who have applied for graduate study, who have accepted admission, and who have completed the program.
- The future of the whole field of study in terms of scientific and scholarly trends and in terms of national, state, and regional needs.
- The national, statewide, and regional contribution of each doctoral program, viewed in the context of the number of other strong programs, whether or not they are operating below their desirable size, and, in general, whether suspension of a program at the institution would have a serious adverse effect on opportunities for graduate study in the nation, state, or region.
- The comparative advantage of the institution in the field—that is, the ability of the institution to make a particular contribution to the field in question because of special factors such as a long tradition of good work in the subject or an unusually strong library resource.
- The interactions between graduate study in the field in question and graduate work and scholarship in other fields at the institution, and the likely effects of suspending work in the field on other programs and faculty members, bearing in mind the need for a certain minimum coverage to maintain an active science tradition.
- The interaction between graduate study in the field and the quality and variety of undergraduate offerings in the same field in the institution.
- The costliness of work in the field, measured in terms of instructional costs, student support, library costs, space costs, instrumentation, and the like. [8]

Even universities with strong graduate programs will need to evaluate them as an essential step in clarifying the institution's role in graduate education. In many cases graduate programs have not been subjected to such intense scrutiny. By rethinking the considerations that should properly govern the size of graduate programs, universities and departments could well strengthen their own positions. Size of enrollments should no longer be the dominant consideration; smaller programs could mean better programs. Universities and state governments could help keep the research tradition alive by adopting flexible and imaginative policies for allocating faculty positions, and not simply by relying on enrollment trends. The academic science system would have an easier time adjusting to the psychology of the "steady state" if federal policies on fellowship and traineeship support were less subject to rapid fluctuations. The sharp cutback of federal fellowships—the form of assistance that typically enables the student to pursue his or her own intellectual interests without interruption—has contributed to declining interest among gifted students in undertaking and/or completing doctoral programs.

The rising costs of research in a number of fields suggest that the user-group concept may have to be extended beyond the very large-scale facilities to which it now applies (e.g., large accelerators, astro-

nomical observatories, oceanographic facilities, atmosphere or environmental laboratories, etc.). Computational facilities are likely candidates for regional or other sharing arrangements among universities. Containment facilities for recombinant DNA work are another example; although hardly in the class of a large accelerator, containment facilities are clearly beyond the present capacities of many university biology departments. The user-group concept offers advantages and disadvantages. Adoption of such sharing arrangements may be the only way for some universities to sustain research efforts in a given field; graduate programs could make use of shared facilities and thereby retain exposure to research on the frontiers of a field. On the other hand, regional facilities may pull students away from the home campus, limit the students' training to a narrow specialty, and give students only a subordinate role in the use of facilities.

There are many areas of modern science where "little science" research can fruitfully be done, and on-campus research should be preserved where possible because the student's exposure to the research process is enhanced. But this may not always be possible and the alternatives need careful attention. New arrangements involving regional research centers, national laboratories, or local industries might have to be developed for both teaching and research purposes. Once again, the experimental areas of science are likely to be particularly affected. If academic science and engineering were to become predominantly theoretical, with experimental research done elsewhere, what would happen to the quality of academic research? Of teaching? The user-group mode has worked remarkably well where the cost and scale of the activity made cooperation the only practical method of conducting research in the field and also generally afforded university scientists the leadership role in planning the research program. There will be greater difficulties in making the concept work with less costly facilities, and harder choices need to be made.

The establishment of new research institutes, or the expansion of existing ones, seems bound to involve structural changes for teaching and research. The best of the institutes might assume a teaching role at the doctoral or postdoctoral level (like the Rockefeller Institute for Medical Research, which became the Rockefeller University, or the Carnegie Institution of Washington, D.C.). Perhaps a postdoctorate period might become the norm for research-oriented PhDs in nearly all fields, and career patterns could evolve in ways that resemble the apprenticeship stages of scientific career development in some European countries.

While we will not suggest possible scenarios for the future, we do see the prospects for rather distinct lines of development springing from these new complex and conflicting trends. A great many factors will influence the course of events, including the uncertain capacity of policy makers to help shape the outcomes. A pattern similar to the present

system is one possible outcome, with graduate education and research of high quality widely scattered among many universities across the country. A pattern of substantially diminished doctoral-level work in many institutions is a second possibility, with a relatively few universities engaged in extensive doctoral-level training and associated research activities. A third potential outcome is a continuation of the present pattern of numerous doctoral programs, but all of them reduced in quality, and the general standards of the educational system in decline. Many variations on these themes are possible. Many adjustments will take place in a free-market process of adaptation; yet governments are so deeply involved that a "pure" market model is inapplicable. The challenge is to think hard about desired outcomes, about the steps that should be taken, and when, and by whom.

Changing Authority Relationships in Academic Science

Before World War II, academic science was generally a low-cost activity; it was supported through a traditional pattern of limited outside support and the university's own resources. The system was stable. Progress was made in a number of fields, but U.S. academic science could not generally be regarded as preeminent in the world. The higher education enterprise was limited to a relatively small sector of the population. World War II dramatically transformed the role of the universities; they were drawn into the defense effort as vital national assets and the pattern persisted into the postwar era. Universities became the large-scale recipients of federal funds for research. Meanwhile, the higher education enterprise had begun to expand greatly; the emphasis was on growth—in facilities, staff, enrollments, and other dimensions. The expansionary era, stimulated by federal and state governments, foundations, the universities themselves, and public expectations, concealed many basic issues of governance in the system as nearly all parties found common ground in promoting growth.

It was obvious that this growth could not go on indefinitely. The university research effort could not continue to produce ever-growing numbers of PhDs in the expectation that each succeeding group of new teachers/researchers would replicate themselves to staff still more new graduate programs and science departments. Toward the end of the 1960s this hard reality began to set in and the fundamental issues could no longer be avoided. What were the terms and conditions under which government supported research in the universities? What exactly did the government buy in funding academic research—specific research projects, a strong higher education system capable of high quality research in general, or something else? Who should pay for what in an of-

ten triangular relationship involving the federal government, the state government, and the university? What broader responsibilities did the universities assume as a result of receiving federal research funds? These and many other questions arose in a variety of contexts—within universities, in the dealings of universities with state governments, in dispute with federal auditors. In the meantime, the administration of higher education was growing vastly more complex: Mass higher education became a reality, vast new undergraduate student aid programs were adopted, and services in addition to research which universities provided society became the focus of public interest. Research was but one aspect of the university's activities and not always the one most understood or valued by the interested public.

The confusion over the proper modes of governance for academic science can begin to be clarified by recognizing that public and congressional involvement in research policy is likely to grow. The decline in confidence in virtually all social institutions that has been a prominent feature of national life in recent years has also affected the universities, which have been subject to growing demands for accountability in the expenditure of public funds and more responsiveness to broad social concerns—including equal employment opportunities, occupational health and safety, protection of the rights of human subjects in research, and other important social objectives. These pressures can be expected not only to continue, but to grow stronger. The decline of public confidence in universities has not been accompanied by a decline of confidence in science, a fact which helps account for continuing high federal R&D expenditures in universities.[9]

Public concern over the technological applications of science has grown.[10] Technological and scientific advances generate potentially harmful side effects or at least pose perceived threats that have often led to public concern and to demands for controls over science and technology. The current list of such research concerns includes human genetics, measurements of intelligence and achievement, research involving human or animal subjects, biochemical genetics, and behaviorial modification by electrical stimulation, surgery, or drugs.

What is striking about such current debates is the extent to which the Congress, state and local authorities, the media, and the public have become involved in the decision-making process. The current dispute over recombinant DNA in various parts of the country is only the most striking instance. Other examples include the fight over the California nuclear referendum in 1976 and the controversy over Columbia University's triga reactor. All suggest the likelihood of growing public involvement in such complex socio-political-technical issues. The scientific community, and the university scientists in particular, have a large responsibility in the future to find new ways to educate the public and involve lay citizens in decisions that earlier would have been considered

the exclusive province of the experts.

The question of both lay and expert control over research will present issues of increasing complexity. Conflicts of basic values will often be involved. Assessments of the potential harm done by pursuit of certain lines of research are extraordinarily difficult. Fear of the unknown and fear of the consequences of knowing could open the way to at times irrational and even demagogic efforts to control research. On the other hand, the insensitivity of some scientists in their insistence on the primacy of a single set of values has complicated efforts to arrive at reasonable solutions. Social control will probably be more direct and detailed in the future than in the past and may change the character of research by inhibiting some lines and by raising costs. It will be important for the nation to take steps to protect the working conditions of academic scientists from unreasonable restraints or maladroit administration of regulations. The withdrawal or threatened withdrawal of federal funds as a means of enforcing compliance is an extremely clumsy instrument of policy. As an example, failure to provide sufficiently for handicapped students can cause withdrawal of funds for research on air pollution. A better system of sanctions is needed, relating penalties more realistically to offenses.

In quite another area, state governments will need to clarify their responsibilities in the support or performance of academic science. Indeed, the importance of state policy to the future of the entire academic research effort is one of the major and unexpected findings of this study. The volume of state support for the general budgets of state universities, and the terms and conditions of this support, are critical to the course of academic science in the public universities. State funds constitute the main source of salaries and general operating expenses. A high but hidden portion of the cost of research in public universities is covered by these operating funds. In the long run, these state appropriations will be a major factor determining the size and quality of the research effort in the public universities. As state assistance to private universities increases, the future of the research effort there will also be affected.

In most states the investment in higher education has become a major state undertaking, and planning and rationalization of the entire effort has become a political imperative. In the competition for state funds, the research and graduate functions will undergo particularly rigorous scrutiny, and their future will be a subject of lively controversy in many states. Our site visits suggest the likelihood of increasing stress and conflict in this area. The question of authority has arisen in acute form: Who can or should control the size of graduate education and academic science programs? Individual departments within a given university? State coordinating bodies? The university regents? Or, in the case of the multicampus university, the management of the univer-

sity-wide system? There will be no uniform answers, but the fact that such questions have arisen already points the way to sharper conflict in the future.

The effects of state and federal policy are now so interwoven in so many ways that conflicts in their policies pose many difficulties. For example, the federal government pays a substantial portion of the indirect costs of research. By doing so, the federal government covers costs—amounting to at least a quarter of a billion dollars—that would otherwise need to be paid by the states. State practices differ on how this sum is treated: Is it state money that is reallocated to other state educational (or other) purposes? Should it be returned by the campus that "raises" the funds or should it belong to the university-wide system as a whole? When the states act as go-betweens for federal civilian R&D funds, they do not customarily pay indirect costs even though the federal agencies ordinarily would.

Strains within the universities, and in their traditional modes of governance, have begun to pose basic problems as well. The universities were traditionally governed by a thin layer of administrators with limited powers, and most basic academic decisions were made by the individual university departments. Substantial changes have occurred: Universities have developed sizable middle-level bureaucracies in recent years. Interdisciplinary programs and institutes have grown up outside regular departmental structures, requiring a different style of management.[11] The growth of large-scale projects within universities, largely but not entirely the result of an increasing federal emphasis on "targeting" research, has tended to create a larger role for central management in the institution. The greater the degree of research complexity, the less the qualifications of any single investigator or the scientific merit of any single proposal will determine whether an award is made or how a project should be organized. What do become important are such factors as the adequacy of the human and material resources of the university, the intellectual commitments of large numbers of people, and the strength of the administrative structure for the undertaking. Central administrations will take the initiative in some of the large-scale projects, and central review and approval becomes necessary for any proposal. Faculty members will increasingly resent the fact that more decisions are made centrally, and disputes over the processes by which decisions are made and over the wisdom and equity of the decisions are bound to increase.

Another consequence of the expansion of large-scale interdisciplinary research may be a substantially greater involvement of professional schools in the projects—law schools, schools of public administration, business schools, and schools of design and architecture. The differences in tradition, outlook, and approach between professional schools and the arts and sciences faculties are likely to add to the complexity of

administration and to the frictions between faculty and administrators.

Targeting and large-scale projects seem bound to lead to important shifts in the style of university operations and the administration of research. The entire peer review process—the traditional method of deciding project awards—may become severely strained. When competition is among individual scientists, awards are based on the capability of the individual and the scientific merit of the proposal; this award process is almost completely nonpolitical. In the case of very large awards, however, the process tends to contain greater political elements, since the stakes are high for both the competing universities and the communities involved. Over a period of time this could serve to undermine scientists' confidence in the award system and eventually lead to a loss of public and congressional support.

The challenges to the peer review process may in any event arise more sharply in the future. With limited funds, there will be more "losers" to complain about unfair treatment. As one ingenuous faculty member observed during a site visit interview: "Peer review used to be fine. I'm all for peer review as it worked before. But now they are turning down everything, and good scientists are not being supported. Something is wrong." We believe that it will be particularly important to protect the integrity of the peer review system in those areas where it has worked well—in the traditional disciplines where scientists can evaluate the merits of competing proposals with a high degree of reliability. And in those areas where peer review cannot operate in its traditional form—in the large-scale, interdisciplinary projects involving broader judgments than disciplinary competence—new procedures need to be devised that embody objective, professional standards and criteria. Different kinds of staffing within federal agencies may be required to administer such large-scale programs; the program officer from a traditional discipline, working largely on his own, is inadequate. The new procedures should draw on competent outsiders to advise on large-scale projects, guarding against potential conflicts of interest.

Universities, in short, are facing severe internal stresses, as pressures from the outside and from within make the job of managing them more difficult. Adversary relationships between faculty and central administrators—traditionally a part of academic life—appear likely to deepen in the future. This does not mean that effective university management will be impossible. But creating and implementing new conceptions of university governance will prove an exceptionally challenging assignment in the coming decade. The framework is complex—public awareness of research developments, pressures from the federal government, state government planning activities, the incorporation of new large-scale undertakings while protecting small-scale scientific activity, faculty disenchantment (possibly leading to unionization movements in some cases), and other elements. And the era of rapid growth is over.

Innovation now must be by substitution rather than by expansion.

Changes in the universities' relationships with other R&D performers is another aspect of the situation. New forms of collaboration among government, industry, and universities may emerge, for example, in the energy field. The issues that arise will perhaps relate not so much to definition of the proper sphere of industry, universities, and government as separate entities, as to new modes of interrelationships among these sectors. Novel organizational structures can probably be anticipated, along with new modes of management and new problems of defining the rights of the parties to the fruits of research.

Universities have had much experience in adjusting to changing circumstances. David Henry's review of such institutional challenges concludes that adjustment has been a prevailing way of life through the boom of the 1920s, the depression of the 1930s, World War II, the postwar GI bulge, and the heady expansion of the 1950s and 1960s.[12] Today, universities are again deep in the process of adjusting to new circumstances. The future of research in the universities has been shaped by many factors and forces at different levels of government. An essential strength of the system has been pluralism, even though it has occasionally veered toward anarchy: No single overall centralized authority can determine the future. We believe the pluralistic process has great strength and has contributed to the vitality of the system. Government, universities, industry, foundations, and the public all have a stake in the overall quality of the U.S. science effort. They should properly play a part in shaping that system in the future. American science remains strong, but now is the time to take prudent measures to protect that strength.

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1. See Dael Wolfle, *The Home of Science: The Role of the University* (New York: McGraw-Hill, 1972), on the decision to avoid building up a small number of large-scale scientific research centers in the nineteenth century. Contemporary observers felt, and many later observers agreed, that it was a safer path for the nation to build up a much broader base of scientific competence in a substantial number of universities.

2. National Board on Graduate Education, *Final Report, 1975* (Washington, D.C.: National Academy of Sciences, 1975).

3. Robert G. Gilpin, Jr., *France and the Age of the Scientific State* (Princeton, N.J.: Princeton University Press, 1968).

4. Edward Gross and Paul V. Grambsch, *Changes in University Organization, 1964-71* (New York: McGraw-Hill, 1974), p. 205.

5. See David E. Drew, *Science Development: An Evaluation Study* (Washington, D.C.: National Board on Graduate Education, June 1975).

6. See the Bell Report, quoted in U.S. Congress, House Committee on Government Operations, *Hearings Before the Subcommittee on Government Operations*, Part I, Eighty-seventh Congress, Second Session, 1962, pp. 192, 233.

7. Ibid.

8. "Meeting the Needs of Doctoral Education: Statement of Policy and Proposed Action by the Regents of the State of New York" (Albany: New York State Education Department, 1973), p. 25 (adapted from Princeton University Priorities Committee Guidelines for 1972).

9. National Science Board, *Science Indicators: Report of the National Science Board, 1975*, NSB-75-1 (Washington, D.C.: National Science Foundation, 1975), pp. 143-151. See also National Science Board, "Science at the Bicentennial: A Report From the Research Community," *Report of the National Science Board—1976*, NSB-76-1 (Washington, D.C.: National Science Foundation, 1976), pp. 82-92.

10. *Science Indicators*, Ibid., p. 151. "Science at the Bicentennial," Ibid., p. 92.

11. See S.O. Ikenberry and R.C. Friedman, *Beyond Academic Departments* (San Francisco: Jossey-Bass, 1972).

12. David Henry, *Challenges Past: Challenges Present* (San Francisco: Jossey-Bass, 1975).

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